Proceedings of the Conference on Natural Regeneration Management

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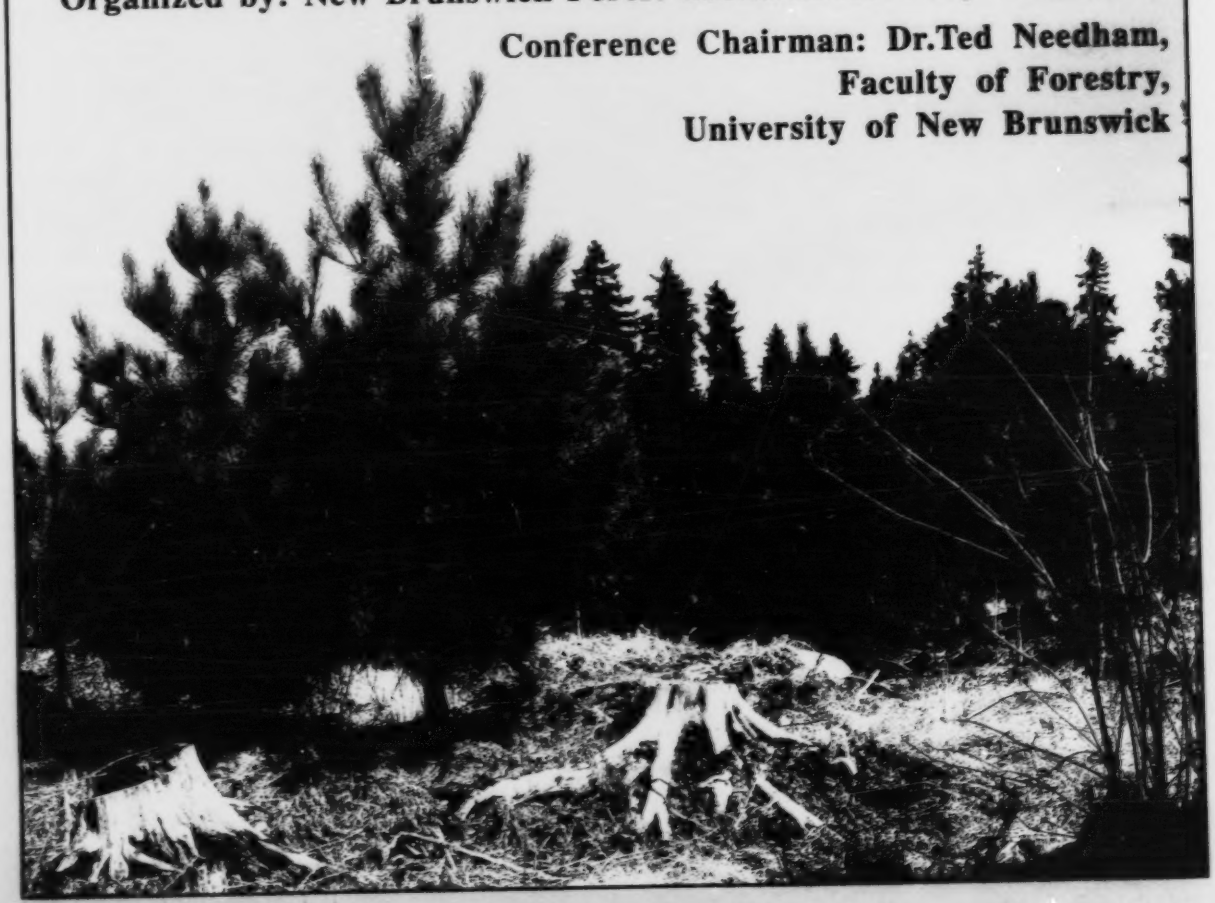
Organized by: New Brunswick Forest Research Advisory Committee

Conference Chairman: Dr.Ted Needham,
Faculty of Forestry,
University of New Brunswick



Forestry Canada Forêts Canada

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PROCEEDINGS OF THE CONFERENCE ON NATURAL REGENERATION MANAGEMENT

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TABLE OF CONTENTS

Page

Opening Remarks
David MacFarlane 5

Use of an Ecological Classification to Evaluate Regeneration and Competition Problems After Clearcutting in northwestern Quebec
Brian Harvey and Yves Bergeron 9

Predicting Natural Regeneration Abundance with a Productivity-Oriented Site Classification
Vince Zelazny and Michael Hayter 25

Variations in the Abundance of Advanced Fir Regeneration in Principal Fir Ecological Types of the Balsam Fir-White Birch Domain in Central Quebec
Louis Bélanger, Sylvie Côté, and Stéphane Marchand 43

Prediction of Advanced Regeneration: A Quebec Experience
David Chamberlain 55

Natural Regeneration from Sprouts and Advanced Growth
David M. Smith 63

Effects of Forest Floor Disturbance on Soil Seed Banks, Germination and Early Survival After Clearcutting a Northern Hardwood Stand in Central New Brunswick
Mark Roberts and Hongyun Dong 67

The Effects of Full-Tree and Tree-Length Harvests on Natural Regeneration and Seedling Microenvironments
Bryce McInnis and Mark Roberts 85

Natural Seed Regeneration of Black Spruce (*Picea mariana*) Stands in the Quebec Boreal Forest
Réjean Gagnon, Hubert Morin, and Hélène St-Pierre 103

Advance Growth Abundance and Regeneration Patterns After Clearcutting in Quebec
Jean-Claude Ruel 115

Page

Growth Performance of Mature Second-Growth Black Spruce in the Saguenay-Lac St-Jean Region, Quebec: Preliminary Results
Jean-Martin Lussier, Hubert Morin, and Réjean Gagnon 133

The Establishment and Early Growth of Red Spruce and Balsam Fir Regeneration
Patrick Strauch 147

The Role of Advance Growth in Regeneration of Red Spruce and Balsam Fir in East Central Maine
William Davis 157

Natural Regeneration Assessment Methods for Quality and Quantity
David Maass 169

The Influence of Stocking of Regeneration on the Yield of Naturally Regenerated Jack Pine and Black Spruce Stands
René Doucet 181

Herbicide Technology for Securing Naturally Regenerating Stands
Maxwell L. McCormack, Jr. 193

Early Response of Balsam Fir (*Abies balsamea* (L.) Mill.) to Precommercial Thinning in the Context of Site Quality
Russell D. Briggs and Ronald C. Lemin, Jr. 201

Fill Planting to Achieve Yield Targets in Naturally Regenerated Stands
Ted Needham and Stephen Clements 213

Identification and Economic Evaluation of Stand Establishment Strategies
Stephen Clements and Ted Needham 225

Commercial Thinning in Newfoundland
Bill Clarke 237

Forest Regeneration Options in Boreal Forests
David G. Brand 245

Appendix I - Program 255

Appendix II - List of Participants 257

OPENING REMARKS

David MacFarlane
New Brunswick Department of Natural Resources and Energy

I would like to outline briefly the history of forest renewal activities on New Brunswick Crown land and some of the trends and directions that can be expected in the future with regard to both natural regeneration and reforestation. I suspect our experience has been similar to that of other provinces and organizations.

New Brunswick initiated a forest renewal program in the mid-1960s. Planting was the only activity undertaken and the effort was really an operational trial.

In the mid-1970s, the first federal-provincial forestry agreement was signed. Forest tree nurseries were constructed and reforestation was dramatically expanded.

Subsequent federal-provincial agreements have maintained the forest renewal program at approximately 17 000 ha/yr. This level maximizes the allowable cut effect. There are now proposals to double this level of treatment in order to increase the wood supply in future years.

In the early years of the expanded forest renewal program, management of natural regeneration was a very minor component. Planting was the major activity - advance natural regeneration was either ignored or attempts were made to eradicate it.

In the mid-1970s, when the planting program was dramatically expanded, there was an abundance of cut-over available with virtually no natural softwood or hardwood regeneration present.

After these areas were planted, sites available for planting had some level of natural regeneration. Attempts were made to eliminate the natural regeneration by burning and site preparation. Only prescribed burning offered any real success. However, prescribed burning was used on only very small areas. Plantations begun in the late 1970s were often overdense because of the large number of stems resulting from planting approximately 2,000 seedlings/ha, as well as the natural regeneration that was present on the site.

Over the years, there has been a gradual change in the ratio of planting and thinning. Spacing or thinning of natural regeneration is now a significant part of the overall forest renewal program as can be seen in 1989, when spacing and planting levels were almost identical.

What is the natural regeneration status of cutovers in New Brunswick? Since 1982, detailed data have been collected on all cutovers (not designated for basic silviculture) 5 years after harvest. The data shown (on this overhead) are based on surveys of approximately 30 000 ha of Crown forest land. I expect the same data would apply to private land.

As can be seen from the table, all untreated cut-overs have more than 40% stocking of commercial species. More significantly, 96% of the areas are over 60% stocked. It should be noted that the stands we are harvesting today are, on average, about 65% stocked (based on crown closure).

The softwood stocking is somewhat less, as would be expected. Even here, 75% of the area is over 60% stocked with commercial softwood species. From the perspective of wildlife habitat and general species diversity,

one might be uncomfortable if the softwood figures were any higher. Higher softwood values would indicate a species conversion that could be cause for alarm. Nearly 20% of our harvest is hardwood, so we would not expect nor want softwood stocking levels to be higher than those shown.

In short -

(a) All untreated cut-overs are well stocked with commercial species;

(b) Some areas are not fully stocked with softwoods as is consistent with the nature of the stand composition currently being harvested;

(c) While full stocking of cut-overs is evident, there is no indication of massive conversion from softwood to hardwood or hardwood to softwood - *i.e.*, the existing stand composition and diversity is being maintained.

The average height of this regeneration is 1.2 m for softwood and 1.75 m for hardwood. Softwood height is approximately 85% of the height growth obtained from the plantation 5 years after treatment. There are still questions that must be answered regarding natural regeneration and potential development. Such things as predicting the abundance and quality of natural regeneration, impact of harvest method on advance and quality of natural regeneration, impact of harvest method on advance regeneration, impact of site quality on natural regeneration, etc. Most of these items will be addressed by speakers over the next 2 days.

Forest management in Canada tends to get caught up in a numbers game. Planting trees is commonly associated with good management. Planting even more trees is better management. This myth is reinforced to some extent by the media information that was and is still being put forward by industry and government. There is a danger that this same numbers game could apply to spacing or thinning of natural regeneration.

We must get away from the concept or thought process that a harvest block is either planted or left for thinning at some future date. The goal presumably is to achieve a certain defined level of forest renewal with specific goals for expected volume and piece size, and species group over a given period of time. I have referred to "forest renewal" a number of times this morning. I believe we should use this term exclusively rather than reforestation or spacing or thinning.

Forest renewal in New Brunswick, in most cases, means enhancing the natural regeneration already in place. This means a combination of planting and thinning rather than one or the other. At the lower stocking levels, a so-called full planting effort may be warranted; at the upper stocking levels, spacing and cleaning may be the main treatment required. In a majority of harvest blocks, however, both treatments will be required to achieve a fully stocked stand as economically as possible and with the least impact on the environment.

There are a number of advantages to the plant-space approach to forest renewal. For example:

- it is less costly than full planting;
- it has less impact on the environment;
- it takes advantage of advance regeneration resulting from either clearcut, shelterwood, or selection harvest;
- there is greater opportunity to develop mixedwood forest, if desired;
- it may result in a lesser requirement for herbicide treatment;

- it provides an opportunity to plant "improved" seedlings;

- it is more in harmony with nature, rather than controlling nature.

The idea of planting and spacing is not new; it has been around for some time. A number of forest managers in New Brunswick, in fact, have been advocating this concept for the last few years. Old ideas, however, are sometimes difficult to change. I believe that now is an opportune time for change. By taking advantage of the natural regeneration present on a site, the forest renewal aspect of forest management can be achieved in the most economical and environmentally acceptable fashion. This results in a future forest that will provide the wood fiber, wildlife habitat, and aesthetic qualities that both the forest industry and the public expect and will require in future years.

Many of the questions concerning the management of natural regeneration will be addressed over the next 2 days.

I would like to thank you for your attention and I look forward to the ideas and information that will be presented on this important topic.

USE OF AN ECOLOGICAL CLASSIFICATION TO EVALUATE REGENERATION AND COMPETITION PROBLEMS AFTER CLEARCUTTING IN NORTHWESTERN QUEBEC

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INTRODUCTION

At first glance, the reference to "problems after clearcutting" in our title may not appear to correspond with the section theme of prediction of natural regeneration. However, I hope that the presentation of this research will contribute to the understanding of natural regeneration distribution both before and after harvesting.

Natural regeneration management is indeed a pressing topic in the forestry sector of Quebec, as in other provinces where legislation has designated the forest industry as responsible for forest renewal on Crown lands. The destructive effects of forest operations, both on site and on survival of natural regeneration, have been well documented (Barrett *et al. 1962; Webber et al.* 1968; Frisque *et al. 1978; Froehlich et al.* 1986; Corns 1988). And as companies search for forest renewal alternatives to the simple and costly cut-and-plant approach, greater interest is being paid to advance regeneration and to harvesting methods that favor the survival of this regeneration (Doucet 1988; Ruel 1989).

Numerous regeneration studies have been undertaken in Quebec. Candy (1951) evaluated advance stocking of spruce (*Picea mariana* and *Picea glauca*) and fir (*Abies balsamea*) in mixedwood forests of the clay belt to be 50% and 100%, respectively, while Doucet (1988), studying the entire boreal balsam fir domain, found lower values of 14% and 90% stocking. Frisque *et al.* (1978) put average advance fir densities at 50 000 stems/ha and stocking at 78%.

While these studies present a global image of the relationships between advance regeneration and regeneration present after harvest, they also identify the need for an improved understanding of the dynamic interactions that occur among the tree component, harvest operations, the physical character of site, and vegetation development following harvesting. While it is possible to generalize about these interactions over a large area, such as the northeastern United States and eastern Canada, it is also important to study the problem on a more reduced area to limit the possible effects due to variations in climate, soils, and other factors. Moreover, biophysical land classifications have been shown to provide a valuable framework for studying succession in forest ecosystems (Arno 1982; Host *et al.* 1987). This presentation is an example of one such study. Many of the results have been presented recently by Harvey and Bergeron (1989).

STUDY AREA

Geographical situation

The study was undertaken in Hébécourt Township (79°W, 48°N) of northwestern Quebec (Abitibi), located in the moderately humid Boreal ecoclimatic region (Groupe de travail sur les écorégions, 1989) and in the Amos Lowlands, according to the ecological regionalization of the Quebec Ministry of Energy and Resources (Thibault and Hotte 1985). Hébécourt is situated in the southern part of the Clay Belt, a large physiographic region characterized by deposits of lacustrine clay left by post-glacial lakes. However, unlike areas further north and west in the Clay Belt where poorly drained soils dominate, well to imperfectly drained clay soils are prevalent in our study area.

Hébécourt and an adjacent township to the north were ecologically classified by Bergeron *et al.* (1983). Initial physiographic stratification of the study area permitted thorough field sampling of major forest ecosystems. Multivariate analyses were used on soil and vegetation variables to identify distinctive landscape units. The classification differentiates 41 different ecological types, each of which represents a landscape unit that is relatively homogeneous in terms of soil properties and chronosequence (Jurdant *et al.* 1977). While the ecological type concept includes the notion of the ecological phase, or stage of vegetation development associated with a type, the ecological type can be identified in the field by the surface deposit and drainage class. The advantages of this type of land classification over a phytosociological approach are readily apparent in studies such as this where forest cover has been removed and ground vegetation has been severely disturbed (Barnes 1986). The classification serves as an ecological frame of reference for the present study and Bergeron's data from mature fir - birch - spruce stands are the information source concerning advance regeneration.

Geomorphology and soils

The northern part of the study area is covered by a vast clay plain which is interspersed with occasional rock outcrops and deep organic deposits. Further south, the Hébécourt Hills are characterized by a series of rugged hills covered to varying depths with reworked till and separated by lacustrine fill. The soils of the area can be divided into three broad categories of surficial deposits (Bergeron *et al.* 1982):

i Fine deposits are dominated by lacustrine clays and silts. Gray Luvisols are found especially on well to moderately well drained sites while Gleysols are generally restricted to imperfectly or poorly drained fine deposits (C.S.S.C., 1978).

ii Coarse deposits include lacustrine sands and reworked moraines or tills. In the region, Humo-Ferric Podzols usually develop on these sites.

iii Organic deposits are characterized by Folisols on excessively drained sites on rock and by Humisols, Mesisols and Fibrisols associated with thick accumulations of organic matter in poorly drained sites.

Climate

The regional climate is continental and cold with a mean annual temperature of 0.4 C and mean annual precipitation of 800-900 mm. The average number of frost-free days is 147 although occasional summer frosts do occur.

Forest Cover

Rowe (1972) places the region in the Missinaibi-Cabonga zone (B.7) dominated by a balsam fir - black spruce - white birch association; however, the abundant rich, mesic clay deposits in the area are occupied by an association of balsam fir - white birch -white spruce. Fire disturbance has had a strong in-

fluence on the forest landscape and is responsable for many of the numerous secondary forests in the region. Trembling aspen (*Populus tremuloides*) stands are very common in the west of Abitibi and tend to develop after fire on mesic clays as well as on abandoned agricultural land. Balsam poplar (*Populus balsamifera*) is found more often on more poorly drained clay soils. On coarse-textured deposits such as tills, white birch establishes after fire in pure stands or in association with aspen or jack pine (*Pinus banksiana*). Jack pine is generally found on coarse deposits and rocky outcrops. Despite these generalizations, species presence also depends on conditions created by past disturbance and seed sources. While some of the forest in Hébécourt Township had been selectively cut in the early part of the 20th century, most of the forest cut in the past decade was virgin, dating back to a large fire in the mid 1700s.

Regeneration Problems

Following the last important infestation of spruce budworm (*Choristoneura fumiferana*) in northwestern Quebec in the mid 1970s (Blais 1983), most of the fir-birch-spruce stands in Hébécourt Township were salvage cut. Whole-tree, mechanical, and manual clear-cutting, with skidding to roadside for limbing, occurred over a period of eight years; no attention was paid to protecting advance regeneration. Inventories conducted in the years following harvesting revealed generally low softwood stocking and often severe competition problems.

OBJECTIVES

Given the availability of Bergeron's field data collected in 1979 and 1980 from stands of fir-birch-spruce, we identified the following objectives:

1. Determine the quantity and composition of advance regeneration in mature fir-birch-spruce stands in Hébécourt Township.

2. Determine the degree of correlation between advance softwood regeneration, basal area and density of stems 5 cm diameter at breast height (dbh) in Bergeron's quadrats.

3. Determine whether differences existed in the rates of advance regeneration between fine-textured surface deposits (lacustrine clays) and coarse-textured deposits (reworked tills).

4. Determine the quantity and composition of softwood regeneration following harvest and its time of arrival.

5. Develop a series of potentially operational land units (Treatment Units) which group the most common ecological types, and compare regeneration and competition levels in terms of these units. (As the ecological type is a relatively fine landscape unit, it often occupies a limited area; it is thus of interest to group ecological types that are similar in terms of physical characteristics and post-harvest succession into larger, yet relatively homogeneous units.)

METHODS

Field Data

Two sets of data are used in the study. The preharvest data were collected in mature, uncut stands in 1979 and 1980 during the ecological classification field work. Detailed vegetation data were collected in 20 0.1-ha quadrats (20 m X 50 m) located in mature stands of fir-birch-spruce (13 on lacustrine clays and seven on reworked tills). Stems over 1 m in height were tallied and dbh measured for the entire quadrat, while seedlings were tallied in 25 quadrats of 1 m^2. Soil pits were dug for profile descriptions, horizon samples

Table 1 Advance softwood regeneration (stems per hectare) under mature balsam fir-white birch-spruce stands. Stocking values presented in parentheses. (Adapted from Harvey and Bergeron, 1989.)

	Lacustrine Clays	Coarse Deposits[1]	All Stations
Balsam fir	51 763a[2]	84 673a	63 282
	(95)	(98)	(96)
White spruce	1 212a	186b	853
	(21)	(7)	(16)
Black Spruce	314a	1 883b	863
	(4)	(27)	(12)
Total	53 289a	86 742a	64 998
	(96)	(98)	(97)

1 Includes reworked tills and thin reworked tills

2 Mean density values followed by the same letter are not significantly different ($p \leq 0.05$), Mann-Whitney test.

were taken for subsequent chemical and physical analyses (Bergeron *et al.* 1982), and other physical site data were collected.

Postharvest regeneration data were collected in 1986 and 1987. Quadrats of 4 m^2 were situated at 100-m intervals along transects located in cutovers. Twenty-six cutovers ranging in age from 1 to 8 years and in area from 10 to 1 300 ha (mean = 125 ha; median = 50 ha) were sampled. Tree stems were counted by height class and species and percent cover values were assigned to all other species. Seedlings were collected randomly in a portion of the quadrats for subsequent aging. Soil pits were dug to determine surface deposit and drainage class and for soil profile measurements; other physical site data were recorded.

Data Analysis

A Spearman rank correlation analysis was performed on preharvest seedling densities with basal area and numbers of stems 5 cm dbh and a Mann-Whitney nonparametric test was used to compare preharvest regeneration data of quadrats on 13 clay sites and seven reworked till sites. Number of stems per hectare and stocking was determined for the preharvest and postharvest data. Hierarchical cluster analysis was performed on postharvest regeneration data to group similar ecological types into nine treatment units. Kruskal-Wallis tests, followed by nonparametric multiple comparison tests, were performed for the treatment units and stocking values were determined for ten tree and shrub tree species. Constancy and mean percent cover were determined for several other species.

RESULTS

Preharvest regeneration

Total softwood regeneration under mature fir-birch-spruce stands averaged 65 000 stems per hectare, of which balsam fir was by far the dominant species (97% of the softwood component). Mann-Whitney tests for differences in preharvest seedling densities in quadrats on lacustrine clay sites and those on reworked tills revealed no significant differences in fir or total softwood regeneration between the two deposit types (Table 1). White spruce had a significantly higher density on clay deposits

Table 2 Spearman correlations of number of seedlings per quadrat, basal area and number of stems ≥ 5 cm dbh for three softwood species

	Basal Area		No. Stems	
	r	α	r	α
Balsam fir	0.188	0.427	0.195	0.409
Black spruce	0.624	0.003	0.825	0.0001
White spruce	0.542	0.014	0.599	0.005

whereas black spruce was more abundant on coarse deposits, but neither species had very high levels of advance regeneration. Stocking levels reflected the same trend, with fir approaching 100% stocking on both types of surface deposits, white spruce reaching its highest level of 21% on clay sites, and black spruce reaching 27% on the till sites.

Spearman correlation analysis was used to test whether seedling densities of each of the three softwood species were correlated to their basal area or number of stems 5 cm dbh in the preharvest quadrats (Table 2). Strongest and most significant correlations were found for black spruce, both for number of stems (r = 0.825, = 0.0001) and for basal area (r = 0.624, = 0.003). A significant correlation was also evident for white spruce. While this suggests that advance black and white spruce regeneration is closely related to their density in the tree layer, taken with the results in Table 1, it also confirms the tendancy, in our study area, for black spruce to be associated with the poorer, coarse-textured soils and white spruce with richer clay soils. The lack of correlation for balsam fir may be explained by the species' prolific seeding and seedling tenacity under shade conditions such that, above a certain level, number of stems or basal area are no longer factors influencing seedling densities. Interestingly, Groot (1984) found a highly significant *inverse* correlation of black spruce regeneration to basal area. However, he was working in predominantly black spruce stands and attributed lower densities of spruce regeneration in stands of very high basal area to mortality of lower, layering-prone branches and to sphagnum mortality.

The question arises whether the spruce budworm infestation that occurred during and after the preharvest sampling period affected seedling densities. Do infestations destroy large numbers of seedlings as well as older trees, or do canopy openings favour new seedling establishment? Our data does not permit anything more than speculation, and the literature contains some contradictions. Vincent (1956) suggested that prolonged infestation killed high percentages of seedlings, especially those over a foot in height. Ghent *et al.* (1957) recorded decreases of 20-65% in spruce and fir seedling numbers between two regeneration tallies in 1950 and 1955 in severe budworm-infested stands and attributed 72% of seedling mortality to coverage by fallen trees. More recently, work by MacLean (1988) in the Cape Breton Highlands suggests that severe and prolonged infestations may reduce seedling numbers to some extent but have little if any affect on stocking. It is doubtful that large declines in softwood regeneration in our study are attributed solely to budworm mortality as extensive harvesting occurred over the same period. Certainly, increased canopy openings caused by defoliation and mortality in the overstory would

Table 3 Advance hardwood regeneration (stems per hectare) under mature balsam fir-white birch-spruce stands. Stocking values presented in parentheses. (Adapted from Harvey and Bergeron, 1989.)

	Lacustrine Clays	Coarse Deposits[1]	All Stations
White birch	7 011a[2]	15 647a	10 034
	(51)	(35)	(45)
Trembling Aspen	159a	0a	104
	(11)	(0)	(7)
Balsam poplar	188a	57a	142
	(5)	(2)	(4)
Total	7 358a	15 704a	10 280
	(60)	(37)	(52)

1 Includes reworked tills and thin reworked tills
2 Mean density values followed by the same letter are not significantly different ($p \leq 0.05$), Mann-Whitney test

explain the relatively high numbers of white birch seedlings under forest cover (Table 3).

Regeneration after harvest

Mean softwood density and stocking after harvest for all quadrats combined were 5 252 stems per hectare (Table 4) and 40%, respectively. Frisque *et al.* (1978) estimated advance regeneration mortality following harvest to vary between 58 and 80%, with highest values corresponding to highest original densities. Candy (1951) estimated that fir stocking diminished from 100% to 70% following cutting; however, his study dates to a period when harvesting was less mechanized. The relatively high decrease in softwood seedling density and stocking in our study may be partially explained by the dominance of fragile clay soils and the method of exploitation, as well as possible budworm effects.

A preliminary comparison of softwood regeneration between the three types of surface deposits (Table 5) reveals total regeneration (all species) to be significantly less on lacustrine clay deposits (well to poorly drained) than on coarse-textured deposits (well to imperfectly drained) and on very poorly drained organic deposits. This difference is partially due to higher black spruce regeneration on the two latter deposit types. Stocking was also lowest on clay sites (30%) and adequate only on combined coarse deposit sites (61%). The relatively high densities and stocking values for fir and black spruce on the

Table 4 Softwood regeneration after harvest

	Stems ha	% total	% preharvest
Balsam fir	4 296	81.7	7
White spruce	292	5.6	34
Black spruce	664	12.6	77
Total	5 252	100	8

Table 5 Postharvest density (stems per hectare) and stocking () for softwood regeneration for three categories of surface deposits

	Lacustrine Clays	Coarse Deposits	Organic Deposits
Balsam fir	2 983a[1]	6 123a	5 635a
	(28)	(53)	(35)
White spruce	154a	487a	468a
	(5)	(15)	(12)
Black spruce	232a	1 207ab	1 875b
	(4)	(8)	(29)
Total	3 369a	7 817b	7 968b
	(30)	(61)	(41)

[1] Mean density values followed by the same letter are not significantly different ($p \leq 0.05$), Scheffe test.

organic sites and the intermediate value for total stocking indicate that spruce and fir regeneration was frequently found in the same quadrats on those sites.

Hardwood regeneration (birch, aspen, and poplar) also decreased after harvesting, primarily due to a 62% reduction in the number of birch stems. What is important to note, however, is the change in the ratio of softwood stems: hardwood stems from 6.3 to 0.8, before and after harvest respectively. This reflects an important change in dominance by advance softwood regeneration to a mixed condition following harvest. This transformation has been observed elsewhere in the clay belt by Jeglum (1983) and Yang and Fry (1981).

Arrival time of seedlings collected in cutovers

Collection of seedlings in cutovers permitted determination of seedling age and time of arrival on the site. In 7- and 8-year-old cutovers, 72-80% of seedlings collected were pre-established while 100% of seedlings collected in 3-year-old cutovers were pre-established. In all, 90% of the 98 seedlings collected 3 to 8 years after harvest originated from advance growth and fir represented 77% of the total (Table 6). Although our sample is small, the data would suggest that spruce regenerated better than fir after harvest and that coarse deposits provide more seeding possibilities than clay sites.

Establishment of "Treatment Units"

Our final objective was to develop a series of potentially operational land units (treatment units) that would group the most common ecological types, and then to compare regeneration and competition levels in terms of these units. Hierarchic cluster analysis was used to group ecological types in the following manner. For 16 ecological types that had at least five observations, mean values of stems per quadrat (summer cutovers) were determined for the following species: balsam fir, white spruce black spruce, white birch, trembling aspen, balsam poplar, speckled alder (*Alnus rugosa*), mountain maple (*Acer spicatum*), pin cherry (*Prunus pensylvanica*) and willow species (*Salix* spp.). From the matrix of 16 ecological types by mean densities for the 10 species, a similarity matrix was computed using the Steinhaus coefficient (Legendre and Legendre 1984). Finally, hierarchic cluster analysis (connexity of 0.50) was performed on the similarity matrix to

Table 6 Number of seedlings established prior to and after forest harvest (from Harvey and Bergeron, 1989)

	Prior to harvest	After harvest[a]	Ration
Balsam fir	71	4	17.8
Spruce spp.	17	6	2.8
Total	88	10	8.8
Clay deposits	65	5	13.0
Coarse deposits[b]	23	4	5.8
Organic deposits	-	1	-

[a] Includes seedlings dated to the year of harvest
[b] Includes moraines and thin organic deposits

evaluate possible groupings among ecological types. This analysis and considerations of physical site characteristics that affect silvicultural operations (drainage, stoniness, presence of outcrops, etc.) formed the basis for defining nine treatment units.

The nine units may be summarized in the following manner: three units are associated with lacustrine clays (TUs 1, 2, and 3); two units are associated with reworked tills (TUs 7 and 8); two transitional units straddle lacustrine sand clay contact zones (TUs 4 and 6); and two units encompass organic deposits, one poorly drained (TU 5) and the other excessively drained (TU 9). A summary description of the nine treatment units is provided in Table 7.

Density and stocking analyses based on the nine treatment units revealed some interesting tendencies (Table 8). Lowest softwood stocking (22%) and density (2 800 stems per hectare) occurred on TU 2 (moderately well to imperfectly drained clays). Next, TU 1 (well drained clays) had a stocking of 36% followed by poorly drained clays (TU 3) and well to moderately well drained reworked moraines (TU 7), both with a total softwood stocking of 43%. In the case of TU 3, however, just over 1 000 stems per hectare of black spruce were found, whereas balsam fir accounted for almost all softwood regeneration on TU 7. Adequate regeneration rates (stocking 60%) were found on thin tills (TU 8) and thin organic sites (TU 9), as well as on the unit grouping mesic thin clays and sands (TU 6). Among these three units, TUs 8 and 9 present difficult conditions for silvicultural operations: thin soils, high levels of rock outcrops and stoniness, steep slopes and ground roughness are common. Moreover, these sites are among the least fertile in the region (Bergeron *et al.* 1982) making silvicultural investments not only operationally difficult but probably least profitable as well.

Highest densities of white birch were observed mostly on units associated with coarse deposits and thin organic soils (TUs 6, 7, 8, and 9) and TU 4, whereas aspen was generally most common on well to imperfectly drained clay soils (TUs 1 and 2). Certain tendencies were also evident for high and low shrub species (Table 9). High densities of speckled alder were associated with poorly drained sites (TUs 3, 4, and 5) whereas mountain maple was most common on well drained sites, especially TUs 1 and 7. Pin cherry was almost exclusively limited to the tills and thin organic units (TUs 7, 8, and 9) and willows were highest on two of the three poorly drained units (TUs 4 and 5).

Table 7. Summary description of nine treatment units.

Treatment Unit	Ecological Types[a]	Texture Horizon B[b]	Depth of Humus Layer (cm) X	SD	MAX	Predominant Topographic Positions	Soil Subgroups[c]
Well drained clays (TU 1)	Clay 2, Aba-Bpa-Pgl	hC, C, SiC	5	3	11	Crests, upper & middle slopes	Orthic & Brunisolic Gray Luvisols
Moderately well to imperfectly drained clays (TU 2)	Clay 3, Aba-Bpa-Pgl	hC, C, SiC	6	3	20	Upper to lower slopes (flats)	Gleyed Gray Luvisols & Orthic Gray Luvisols
Poorly to very poorly drained clays (TU 3)	Clay 4, Aba-Bpa-Pgl					Lower slopes, flats, depressions	
	Clay 5, Aba-Bpa-Pgl	hC, C, SiC	11	8	40		Orthic & Humic Luvic Gleysols, Regosolic & Regosolic Humic Gleysols
	Clay 6, Aba-Pma					Lower slopes, flats, open & closed depressions	
Poorly to very poorly drained sands, clays with seepage (TU 4)	Sand 5, Pma-Aba	hC, C, fS-cS, LS, SiC	9	5	19		Pozolic & Orthic Gray Luvisols, Gleyed Humo-Ferric
Very poorly drained organic deposits (TU 5)	Clay 5[d*], Aba-Bpa-Pgl					Flats, open & closed depressions & lower slopes	Podzols, Fibrisols, Mesisols, Humisols
	Organic 6 fibric, Pma Organic 7 mesic, Lla Organic 6 humic, Pma- Aba	Of, Om, Oh	58	23	>100	Crests, upper & middle slopes (lower slopes)	Gleyed & Orthic Humo-Ferric Podzols
Well to moderately well drained thin clays and sands (TU 6)	Thin clay 2, Aba-Bpa Sand 3, Aba-Bpa-Pgl	fS-cS, SiC, L, LS, CL	7	2	11	Middle slopes,(upper & lower slopes)	Orthic & Placic Humo-Ferric Podzols, Humo-Ferric Podzols with Orstein, Ferrous Gleysols
Well to moderately well drained reworked moraines (TU 7)	Reworked moraine 2, Aba-Bpa-Pgl	SL, LS, L, CL, Si	6	3	16		
	Reworked moraine 3, Aba-Bpa					Middle slopes (upper & middle slopes, flats)	Orthic & Placic Humo-Ferric Podzols (with Orstein), Ferrous Gleysols
Well to moderately well drained thin moraines (TU 8)	Reworked moraine 3*, Aba-Bpa-Pgl						Folisols
	Reworked moraine on rock 2-3, Aba-Bpa-Pgl	L, SL, LS	8	4	16	Crests, outcrops, upper slopes (middle slopes)	
Rapidly drained thin organic deposits (TU 9)	Reworked moraine on rock 3-4, Aba-Bpa-Pma						
	Organic 1, Pma	LS, R	10	6	20		
	Organic 1, Pst						

[a]Ecological types from Bergeron et al. (1983). Each ecological type identifies the surface material, drainage class and forest climax association. (Ex. Clay 2, Aba-Bpa-Pgl represents well drained lacustrine clays with an associated climax forest of balsam fir - white birch - white spruce.) Aba = Abies balsamea, Bpa = Betula papyrifera, Lla = Larix laricina, Pgl = Picea glauca, Pma = Picea mariana, Pst = Pinus strobus.

[b]Texture symbols as follows: C = clay, L = loam(y), R = rock, S = sand(y), Si = silt(y), c = coarse, f = fine, h = heavy; Of, Om, Oh = fibric, mesic and humic organic, respectively.

[c]Canada Soil Science Commission, 1978.

[d*] denotes seepage.

Table 8.Mean number of stems per hectare and stocking () for tree species according to nine treatment units (Adapted from Harvey and Bergeron, 1989.)

	TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 9
Balsam fir	6 429ab[1] (36)	2 691b (22)	2 813a (34)	5 887ab (42)	6 000ab (43)	8 194ab (47)	3 775ab (39)	8 448a (74)	9 891a (61)
White spruce	0a -	80a (2)	486a (4)	565a (10)	500a (14)	0a -	441a (11)	345a (11)	870a (4)
Black spruce	0a -	32a (1)	1 076a (13)	1 774a (23)	1 833a (29)	2 361a (29)	147a (2)	776a (7)	870a (22)
Total	6 429ab (36)	2 803b (22)	4 376ab (43)	8 226ab (48)	8 333ab (43)	10 555a (65)	4 363ab (43)	9 569a (78)	11 631a (65)
White birch	3 929ab (43)	1 640b (23)	2 396b (16)	6 210ab (48)	3 167ab (43)	5 972ab (47)	6 373a (59)	4 483ab (52)	8 913a (61)
Trembling aspen	7 143a (57)	4 379ab (31)	590b (12)	887ab (26)	167b (7)	972ab (18)	539ab (14)	517ab (22)	2609ab (17)
Balsam poplar	357a (7)	366a (5)	347a (4)	81a (3)	0a -	0a -	0a -	0a -	0a -
Total	11 429a (71)	6 385a (45)	3 333a (38)	7 177a (61)	3 334a (43)	6 944a (53)	6 912a (53)	5 000a (59)	11 522a (65)

[1]Number of stems per hectare is presented; however, letters next to density values correspond to nonparametric multiple comparison tests on ranks of the TUs. For each species, TUs with the same letter are not significantly different ($p < 0.05$).

Table 9. Mean number of stems per hectare and stocking () for shrub tree species and percent mean cover and constancy () for low competition according to nine treatment units.

	TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 9
Speckled alder	357b[1] (7)	1 131ab (17)	5 764a (50)	3 306a (45)	6 667a (64)	833ab (18)	343b (5)	259b (7)	109b (4)
Mountain maple	7 679a (71)	2 229b (24)	2 014b (19)	806b (13)	167b (7)	3 333ab (18)	8 725a (48)	2 845ab (37)	3 152ab (26)
Pin cherry	0ab -	621ab (10)	0b -	81ab (3)	333ab (7)	972ab (12)	2 451ab (27)	3 534ab (30)	2 283a (30)
Willow spp.	536ab (14)	892b (11)	1 910ab (25)	6 129ab (39)	5 667a1 (50)	111b (6)	1 814ab (16)	1 293b (12)	326b (9)
Total	8 572a (79)	4 873a (52)	9 688a (73)	10 323a (65)	12 833a (71)	6 249a (47)	13 333a (73)	7 931a (59)	5 870a (52)
Raspberry	9 (45)	27 (82)	12 (81)	6 (52)	4 (60)	23 (72)	16 (76)	6 (41)	2 (30)
Blueberry	3 (3)	*[2] (1)	* (5)	1 (14)	2 (23)	9 (19)	2 (17)	9 (40)	9 (37)
Grasses & sedges	10 (29)	13 (79)	24 (94)	21 (77)	27 (93)	4 (44)	2 (55)	1 (41)	* (9)

[1]Number of stems per hectare is presented; however, letters next to density values correspond to nonparametric multiple comparison tests on ranks of the TUs. For each species, TUs with the same letter are not significantly different (p 0.05).
[2]* < 1 % mean cover.

Competition by grasses and sedges followed the general tendancy of speckled alder, showing increasing cover from well to poorly drained clays (TUs 1 to 3) and high cover on the two other poorly drained units (TU 4 and 5). Raspberry (*Rubus idaeus*) competition was especially severe on moderately well to imperfectly drained clays (TU 2), but was also high on other mesic sites. Blueberry (*Vaccinium* spp.) competition was highest on poorer sites (TUs 8 and 9) where grasses, sedges, and raspberry were less abundant.

DISCUSSION AND CONCLUSION

This study, undertaken in the southern part of the clay belt, confirms the results of other studies concerning the impacts of forest harvesting on softwood regeneration. Whole-tree clearcutting and skidding without any measure of protection of advance regeneration causes an important reduction in this regeneration. Moreover, this effect appears to vary in relation to the physical character of the site. For example, we observed lowest regeneration rates on the most fertile sites, the moderately well to imperfectly drained lacustrine clays. These same sites are subject to intense competition by grasses, sedges, raspberries, and other low shrubs. Because these sites are very rich but also very sensitive to problems of compaction and erosion, they deserve special attention from forest managers. When possible, winter harvesting should be given priority in order to protect both advance regeneration and the structure of upper soil horizons. Moreover, because the organic layer serves as an important nutrient reservoir and as a buffer against frost-heaving, scalping of this layer should be avoided during site preparation, such as winter shearblading. Scalping these clays can also cause extreme soil hardening which reduces possibilities of success of seeding or planting operations.

At the other extreme, the two treatment units associated with thin tills and xeric organic sites (TUs 8 and 9) are among the poorest sites in the region, but also the best regenerated after harvest. Silvicultural interventions are probably not as profitable but may not be as necessary either. The physical characteristics of these sites (thin soils with a high degree of stoniness and outcrops, difficult slopes) present operational constraints for forest harvesting and renewal. Rather than forest establishment, the problem here may more often be one of cleaning hardwood and shrub tree competition to ensure free-to-grow status of natural regeneration. An appreciation of these site differences could help planning of silvicultural operations.

It should be noted that this study is not without its peculiarities. First of all, whole tree salvage cutting of fairly large surface areas, with skidding to roadside and no attention made to protect advance regeneration is an extreme situation. Even a slight modification of skidding patterns probably would have increased advance growth survival. Second, the physical and chemical properties of the two predominant surface deposit types of the study area (lacustrine clays and reworked tills) differ considerably. In areas where surface deposits are more homogeneous, the vegetation may manifest fewer differences due to this effect.

One final note concerning forest ecological classifications and mapping: It is evident that one cannot plan forestry activities with physical site information alone. In fact, forest cover maps depicting stand age, composition, density, and height have generally been the mainstay of forest harvesting and silvicultural planning activities, at least in the province of Quebec. Ideally, a combination of the forest cover map with an ecological map depicting more stable site factors would present the best of both worlds; however, experiences in simple overlaying - both manual and digital - of these two types of maps have resulted in unsatisfactory products due to the lack of correspondence between unit boundaries and the multiplication of units.

An approach that holds some promise to resolving this problem is currently being investigated by the Quebec Forest Inventory Service. It consists of circumscribing ecological types during photointerpretation, prior to mapping of forest cover types. In this way, "stable" landscape units - the ecological types - are mapped as relatively permanent units, within which the more dynamic stand units (those that require more frequent attribute and boundary updating) are delineated. The forest ecological map or "carte écoforestière" should provide a valuable framework for achieving a better understanding of stand dynamics, including those related to regeneration, and for planning forest operations.

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PREDICTING NATURAL REGENERATION ABUNDANCE WITH A PRODUCTIVITY-ORIENTED SITE CLASSIFICATION

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ABSTRACT

Data from three sources have been combined in an attempt to gain insight into the pattern of occurrence of advance regeneration spruce and fir in mature stands in northern New Brunswick. These sources include stand, site, and regeneration data collected province-wide in 1986, vegetation and soil data collected between 1985 and 1988 in north-central New Brunswick (the Upsalquitch Site Region), and stand, site, and regeneration data from the same area in 1989.

The 1986 data were used in a stepwise multiple linear regression of advance regeneration density on stand and site variables. The regression identified variables that account for significant variability in the abundance of spruce and fir natural regeneration (r^2= .39 and .44, respectively) in northern New Brunswick.

The regression equations were applied to site classification plot data from the Upsalquitch Site Region in order to derive predicted advance regeneration spruce and fir density for these plots. The predictions were then used to derive estimates of mean density of spruce and fir advance regeneration for the Upsalquitch Vegetation Types (VTs) in order to determine whether VTs could be used to predict natural regeneration abundance.

In 1989, additional counts of advance regeneration were carried out for Vegetation Types of the Upsalquitch Site Region, and these numbers were compared to predictions derived using the regression equations. Observed and predicted abundance of advance regeneration among Vegetation Types is broadly similar. Variables identified in the regression analysis may be used to further refine Vegetation Types for predicting abundance of advance regeneration.

Advance regeneration density predictions associated with modified Vegetation Types will be useful for planning purposes. In combination with managed stand yield predictions, advance regeneration predictions can help guide the silviculturist in choosing areas to treat, harvesting equipment, treatments, and reforestation species.

INTRODUCTION

Natural regeneration is becoming increasingly important in the effort to increase the forested area of well-stocked coniferous stands. In New Brunswick, balsam fir is the principal naturally-regenerating species, followed by black, red, and white spruce.

Various sources (including Godin 1986; Hatcher 1960) have indicated that fir and spruce seedlings and saplings occupying young cutovers are principally of advance-growth origin (*i.e.*, they occupied the ground stratum of the stand **before** harvest), a small number originate from seed in the year of harvest, and a negligible number originate from seed in years following the harvest. Therefore, prediction of postharvest abundance of spruce and fir seedlings can start with predictions of preharvest numbers.

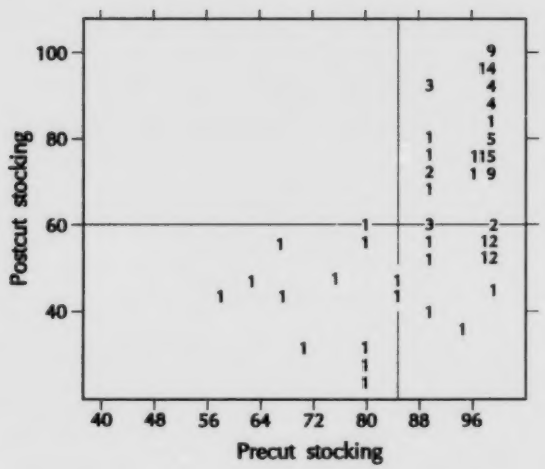


Figure 1 Relationship between percent stocking immediately pre- and postharvest with a variety of harvesting systems. Data from Zelazny (1986) and Frisque *et al.* (1978). Percent stocking data from Frisque *et al.* adjusted upward by 10% to account for difference in stocking standard.

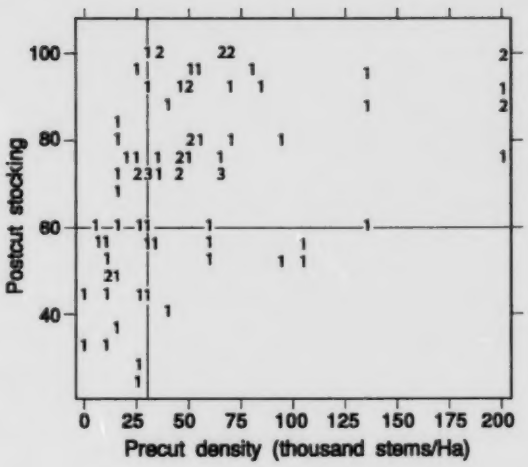


Figure 2 Relationships between preharvest spruce and fir advance growth density and immediate postharvest stocking. Data from Zelazny (1986) and Frisque *et al.* (1978).

However, the seedling occupying a place in an unharvested stand faces numerous obstacles to its survival through a harvesting disturbance. If it is not broken, crushed, uprooted, buried under dense slash, or defoliated in the process of harvesting, then it is still at risk of being frost-killed, dried up or flooded out with the microsite changes that can follow forest harvesting. Its chances of survival are also affected by the harvesting system, the skill of the operator, and the season of harvest. Its size and root development in relation to the forest floor depth and nature of the soil also influence its chance of survival (Place 1955). In view of the inherent variability of these hazards, prediction of 5th year survival of spruce and fir from preharvest measures of advance regeneration abundance is very risky at the **stand level**. It will be difficult to do away with regeneration surveys, no matter how well we develop our ability to predict advance regeneration abundance.

Nevertheless, some rough approximations of immediate postharvest stocking from pre-harvest advance regeneration density or stocking are possible, and such approximations could serve as guidelines when priorizing areas for silvicultural treatment, selecting treatments, or selecting harvesting systems. Figures 1 and 2 demonstrate that a pre-harvest density of approximately 30,000 stems/ha or more and a stocking level of 85% or more results in "adequate" stocking (60% stocking @ 2000 stems/ha) in a high proportion of cases (83% of stands were 60% stocked postcut when precut stocking was 85% to 100%; 84% were adequately stocked postcut when precut den-

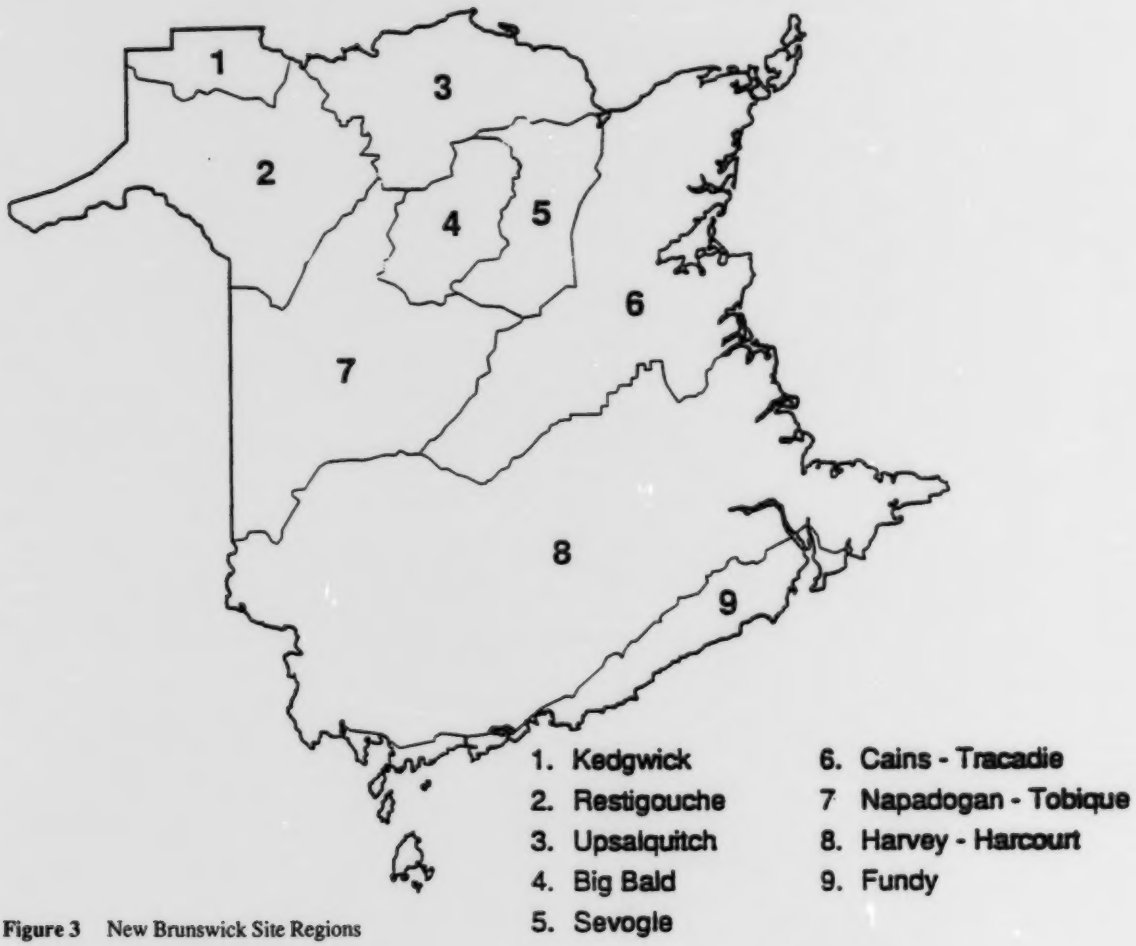


Figure 3 New Brunswick Site Regions

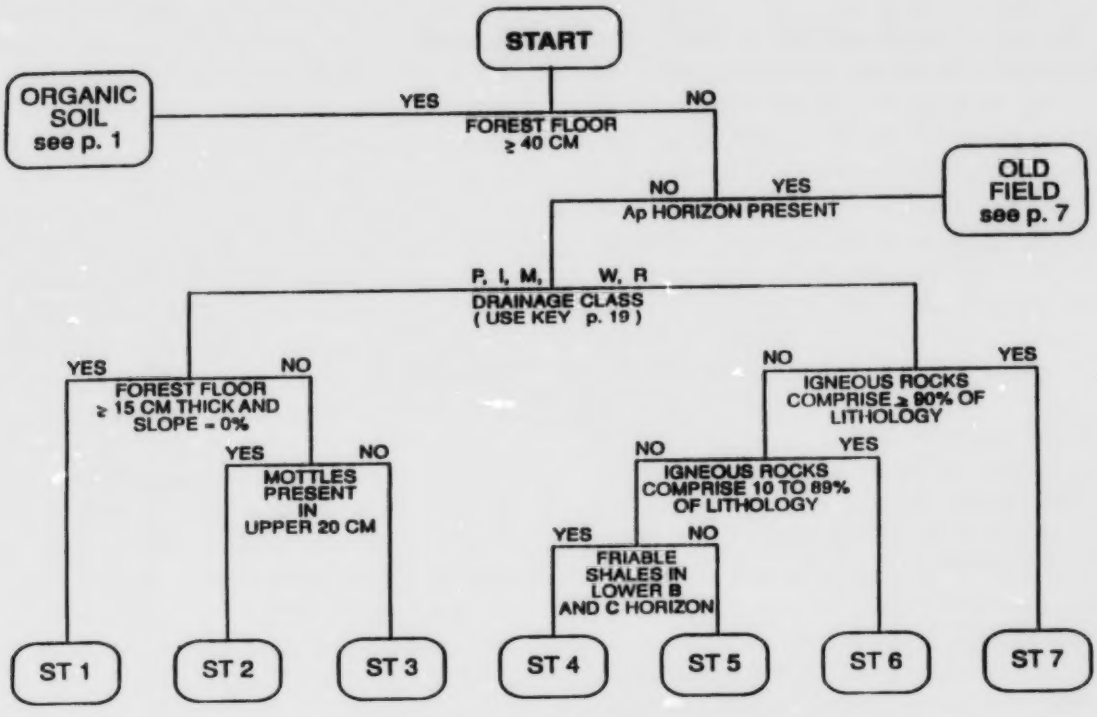
sity was at least 30,000 stems/ha). For this reason, we undertook to develop a system for predicting preharvest advance regeneration density of spruce and fir.

We proceeded under the assumption that there are two important factors influencing the abundance of spruce and fir advance regeneration in a stand. Most influential are the **ecological conditions** that give rise to certain stand types possessing forest floor and understory vegetation characteristics that either promote or inhibit germination and growth of young spruce and fir (Westveld 1931; Hatcher 1960; Place 1955; Godin 1985; Ferguson *et al.* 1986). Secondly, the **condition of the overstory**, and in particular the density of the canopy, influences seed germination by regulating the amount of light and heat reaching the forest floor (Place 1955). According to Godin (1985), in New Brunswick there is a threshold of stand density beyond which heavy shade has the effect of reducing advance regeneration density. These stands typically are two-storied, and have a large proportion of non-merchantable stems (dbh 10 cm).

Naturally, it would be convenient if the advance-growth prediction system could be

Figure 4 Treatment Unit grid for the Upsalquitch Site Region. Treatment units are defined by specific combinations of Soil Type and Vegetation Type.

SOIL TYPE KEY



VEGETATION TYPE KEY

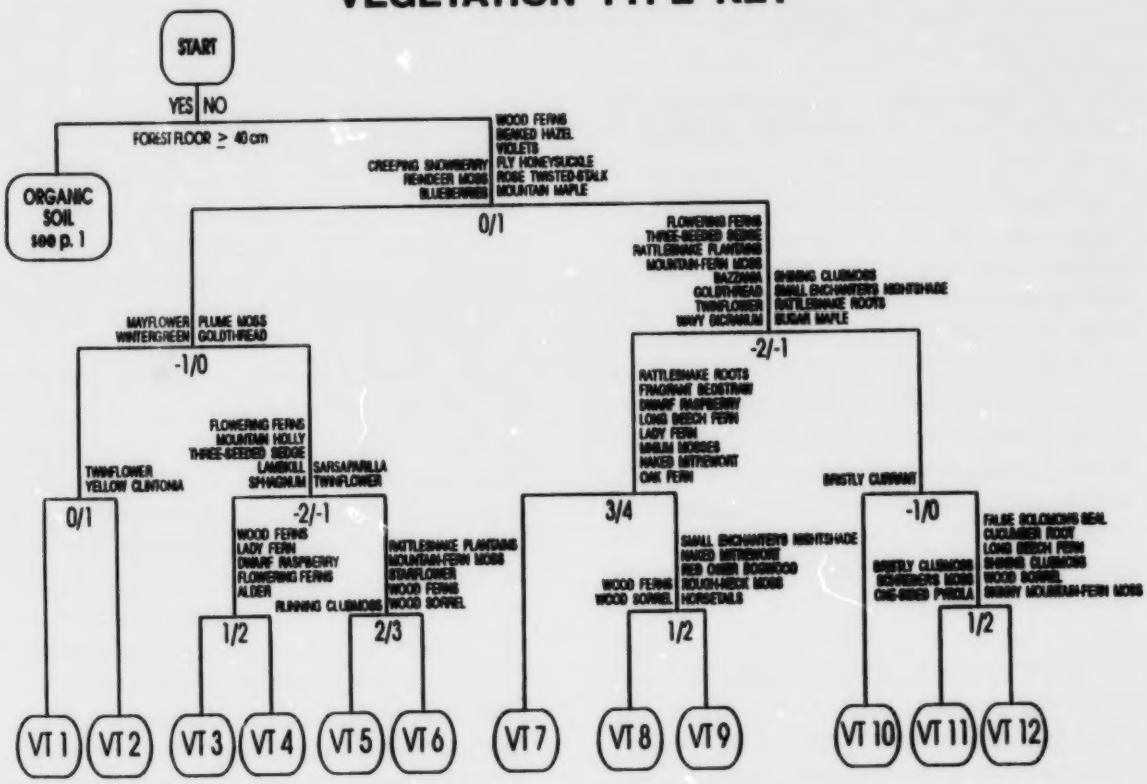


Figure 5 Soil Type (ST) and Vegetation Type (VT) keys for the Upsalquitch site region.

built around existing ecological classifications and forest inventory maps. The focus of this paper is to determine to what extent the existing New Brunswick site classification, and in particular the Vegetation Type classification, is sensitive to the ecological conditions that are used to predict abundance of natural regeneration, and to suggest additions to the existing system to improve the reliability of predictions.

Ecological Conditions: Site Classification

The current site classification program in New Brunswick has been ongoing since 1981. Divisions of the landscape are based on climatic regions (van Groenewoud 1984; Loucks 1962), geology, soils, and vegetation. The operational system consists of two levels: the Site Region (Figure 3), and the Treatment Unit (TU). Site Regions are distinguished on the basis of homogeneous climate and geology. A set of TUs exists for each Site Region, ranging in number from eight to fifteen per Site Region.

A TU is a grouping of ecologically similar site types that have a narrow range of potential productivity for spruce, fir, or jack pine. To identify a TU, the surveyors must classify the vegetation and the soil; each ecologically "possible" combination of soil and vegetation is assigned a TU (see Figure 4). The unit of classification of vegetation is the Vegetation Type (VT), and that of soil is the Soil Type (ST). Both the Soil Type and Vegetation Type Keys (Figure 5) were developed with a view to maximizing the distinctiveness of the classification units in terms of potential productivity. Presently, the majority of TUs have been interpreted for managed-stand yield of at least one species.

The role of vegetation in site classification has long been debated among those involved in site classification. Those opposed to the use of vegetation often insist that the forest is "too disturbed" as a result of past harvesting or fires for the vegetation to be accurately used as an indicator of soil conditions. We have avoided some possible pitfalls by putting the focus of our classification tool on the quantification of mature vegetation communities with emphasis on **species composition** of shade-tolerant species, rather than on **dominance or abundance** of species. Our rationale for this is that dominance can change over time, but species composition of tolerant species is relatively stable soon after full site occupancy is reached (Egler 1954, Drury and Nisbet 1973). Moreover, the presence of a species within a certain site type suggests that the species' ecological requirements of heat, light, water, and nutrients are satisfied. Finding an explanation for its abundance on a site is more difficult, because the reasons may be related to factors unrelated to site quality, such as abundance or scarcity of light, degree of insect infestation, or past disturbance.

Vegetation Type keys were developed with the help of the Cornell ecology programs **Twinspan** and **Decorana** (Hill 1979a, 1979b; Gauch 1982; Kershaw and Looney 1985). Input for Decorana and Twinspan consists of vegetation samples (stands) listing all overstory and understory species present with a measure of abundance, usually a percent cover class. The full set of sample plots should reflect the full spectrum of ecological conditions for the area being described.

The Twinspan algorithm proceeds as follows: first, it ranks all stands along an ecological gradient reflected in the stands' species composition (from poor jack pine-shrub to rich tolerant hardwood-herb, for example) and subsequently **splits** the ranked stands into two groups. The ranking and splitting procedure is repeated on resulting sub-groups many times, until an appropriate number of ecologically-distinct groups is formed. What makes Twinspan especially useful is that each time a split is made the program extracts from each group distinctive species that best characterize the group, and uses them to construct an algo-

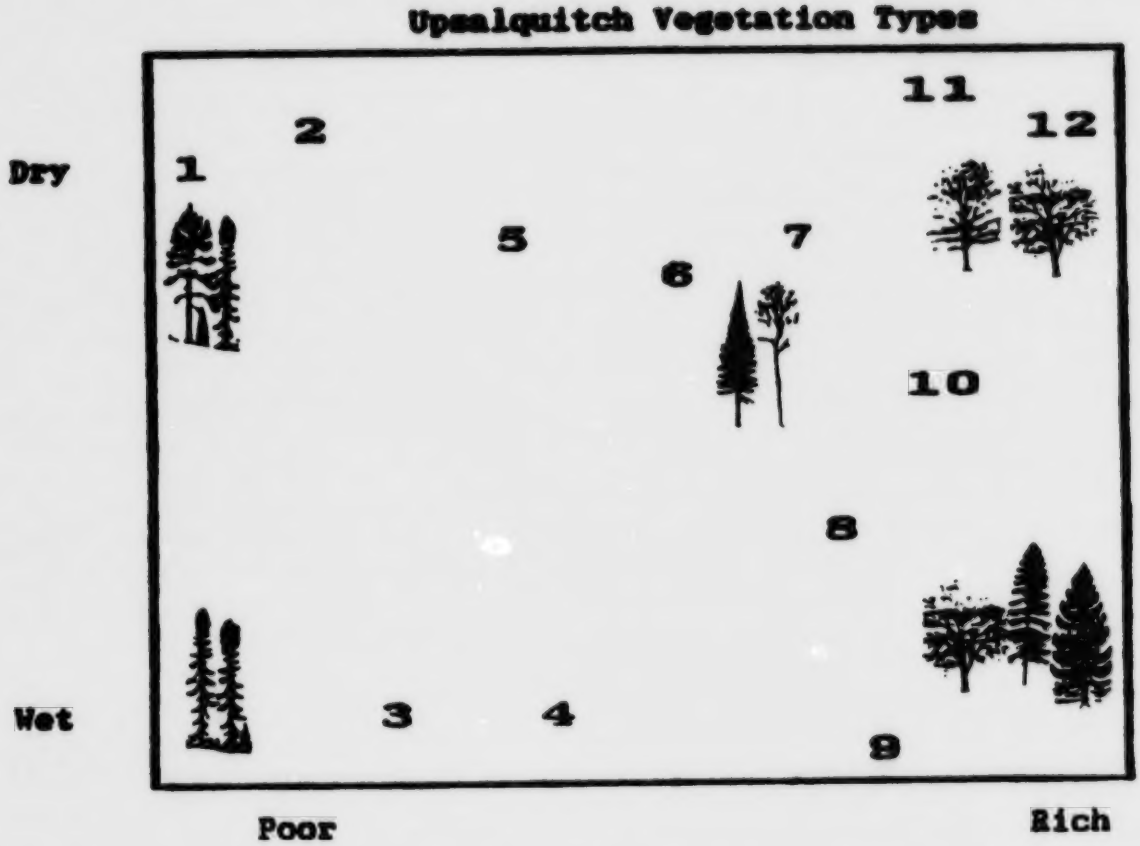


Figure 6 Decorana ordination for the Upsalquitch Site Region. Numbers denote Vegetation Type (VT). Position for each VT is determined by averaging axis 1 and axis 2 scores for all plots.

rithm for classifying new stands (*i.e.*, it develops an open classification). The final product is a key similar to the Vegetation Type Key shown in Figure 5.

Decorana provides additional information about the groups identified by Twinspan. It generates stand rankings much the same way that the ranking portion of Twinspan does. However, it does the ranking twice; the second time it ranks the stands based on the residual variation in the vegetation data left behind after the first ranking. When all stands are plotted on a graph using the two rankings as X and Y axes, a picture emerges (usually called an **ordination** by ecologists) such as the one in Figure 6. When the VT classification of each plot is overlaid on its location in the graph, the relationships among VTs is made clearer than can be seen from looking at the Twinspan-generated key alone. Ecological interpretations may be assigned to the two rankings (ordinations), such that one may represent a "moisture" gradient, and the other a "nutrient" gradient; in this way, VTs may be termed "Moist Rich" or "Dry Poor" according to where they fall on the ordination plot. Similar methods have been used elsewhere in forest site classification (Jones 1987).

METHODS

The task of interpreting a Site Region for natural regeneration abundance would be simpler if we had made estimates of natural regeneration in the mature stands that were sampled in the original site classification effort. We could then have overlaid measures of

abundance of spruce and fir on the Decorana-derived ordination to identify trends of changing abundance with ecological condition, and constructed keys accordingly. **Predicted** natural regeneration abundance could then be validated against **observed** values taken from a second set of observations in key testing.

Instead, we devised a multiple regression model to predict natural regeneration abundance for the original 1986 site classification plots. Subsequently, we validated the model by comparing the predictions with observed natural regeneration abundances in site-classified stands established in 1989. Our study area for this exercise was the Upsalquitch Site Region.

Input for the regression model consisted of advance regeneration counts, detailed microsite and ground vegetation measurements, and overstory measurements taken in mature and over-mature stands. The information was gathered as part of the Cutover Response project undertaken jointly by governments and five forestry companies in New Brunswick in 1986 (Zelazny 1986). Regeneration counts by species and size class were done on 5-m^2 circular plots established at intervals of 25 m along two parallel cruise lines spaced 50 m apart. There were 10 points per line, and a total of 20 per stand. A prism sweep (B.A.F. 2) was done at every second point to determine overstory basal area and density (a total of 10 prism points per stand). There were two site classification plots in each stand, and 78 stands sampled throughout the province.

There were only four stands sampled in the Upsalquitch Site Region, so the input data set was expanded to include stands sampled in Site Regions throughout north-central and northwestern New Brunswick. This was a compromise necessary to represent the range of stand conditions found in the Upsalquitch Site Region. Climatically (at least) this is a reasonably homogeneous grouping of Site Regions.

The unit of sampling for the regression analysis was individual points, rather than stands. We were concerned that by averaging microsite conditions within stands (particularly in heterogeneous stands) we might lose significant information about the microsite-advance regeneration density relationship. Only the points that included a prism tally were used. In total, there were 349 data points from 35 stands in the regression. The 35 stands covered a wide range of site and stand conditions. The regression was carried out using the SPSSPC Regression procedure with the stepwise option. We performed separate regressions on spruce and fir advance regeneration density. Independent variables submitted to the regression are listed in Table 1.

Next, we generated advance regeneration spruce and fir density predictions for the original site classification plots in the Upsalquitch Site Region by submitting the plot data to the regression equations, and solving for predicted density. Many of the variables required for the regression equations were not available for the site classification plots, and had to be estimated. In all cases, however, strongly correlated variables were available (for example, basal area for any species was estimated using percent cover classes). Estimates of forest floor layer (L,F) thicknesses were derived by regression analysis. We recognize that errors in the estimation of independent variables influence predicted advance regeneration density. However, we are satisfied that the **relative** differences across the range of ecological conditions should still emerge from the analysis, and the actual densities will emerge from validation in the field.

In 1989, regeneration surveys were carried out in previously site classified stands in the Upsalquitch Site Region. The purpose of this survey was to determine to what extent advance regeneration abundance was related to

Table 1 Independent variables included in the regression analysis for predicting spruce and fir advance growth density.

Variable Name	Variable
ALD	Density of alder
RAS	Density of raspberry
HAZ	Density of beaked hazel
MTM	Density of mountain maple
STM	Density of striped maple
ERI	Density of ericaceous species
HOB	Density of hobblebush
NWR	Density of northern wild raisin
BRA	Density of bracken
OFR	Density of other ferns
LIT	Depth of the litter (L) layer
FER	Depth of the fermentation (F) layer
HUM	Depth of the humus (H) layer
GRA	Percent cover of grasses
SED	Percent cover of sedges
OHB	Percent cover of herbaceous species
SPH	Percent cover of sphagnum mosses
MOS	Percent cover of other mosses
BABS	Basal area of black spruce
BA2	Basal area of white spruce
BA3	Basal area of red spruce
BA5	Basal area of balsam fir
BA9	Basal area of eastern white cedar
BA12	Basal area of red maple
BA13	Basal area of sugar maple
BA14	Basal area of yellow birch
BA15	Basal area of beech
BA19	Basal area of white birch
BA20	Basal area of poplar
UDENS5	Density of overstory fir (dbh < 10cm)
TOTUDENS	Total overstory density (dbh < 10cm)
HWUDENS	Density of overstory hardwoods (dbh < 10cm)
SWUDENS	Density of overstory softwoods (dbh < 10cm)
BASF	Basal area of spruce and fir
BAIH	Basal area of poplar and white birch
BATH	Basal area of tolerant hardwoods
BATOT	Total basal area of overstory
RBASF	Relative basal area of spruce and fir
RBAIH	Relative basal area of poplar and white birch
RBATH	Relative basal area of tolerant hardwoods
RBABS	Relative basal area of black spruce
RBASPR	Relative basal area of spruce species

Table 2 Allowable error for six advance regeneration density ranges.

Range of mean density		Allowable error
Min	Max	
0	10000	1.0
10001	20000	0.3
20001	40000	0.2
40001	60000	0.3
60001	100000	0.4
100001	200000	0.5

VT. Stands were stratified by VT because we believed that regeneration abundance would be most strongly correlated with VT than with either ST or TU. Forty-six stands were surveyed, representing a broad range of ecological conditions. Each survey consisted of a number of 5-m^2 circular plots in which spruce and fir advance regeneration were counted. The number of plots, *n*, was determined using the following formula:

$$n = \frac{t^2 x s^2}{E^2}$$

where **s** is the standard deviation of mean density, **t** is the two-tailed t value from a table of t values, and **E** is the allowable error times the average density. As the allowable error is reduced, so the precision of the estimate of density increased (as is the number of plots to achieve that error level) according to Table 2.

Greatest precision in the estimate of average density is required at about 30,000 stems/ha. This is the preharvest density threshold above which 60% stocking is usually achieved immediately post-harvest (see Figures 1 and 2).

The 1989 data set was used to validate the advance regeneration density predictions for the original site classification plots that were generated using the regression equations.

RESULTS

Regression analysis helped to identify variables that are correlated with the occurrence of spruce and fir advance regeneration density, and identified microsite and stand conditions associated with abundance and scarcity of spruce and fir regeneration.

Results of the regression are listed in Table 3. The regressions explained 39% and 44% of the variability in fir and spruce advance regeneration density respectively (r^2= .39 for fir, .44 for spruce).

High densities of fir regeneration are related to the dominance of fir in the overstory, the dominance of poplar and white birch in the overstory, the dominance of red spruce in the overstory, and the thickness of the F layer of the forest floor. Low densities occur in stands that have a high density of small-diameter softwoods, abundance of ericaceous species, abundance of certain deciduous trees and shrubs (beaked hazel, striped maple, or sugar maple), or high percent cover of sphagnum mosses.

Spruce regeneration is abundant when black and red spruce form a high percentage of the basal area of a stand and in stands with a high percent cover of mosses (excluding sphagnum mosses). High spruce regeneration density is also correlated with a thick litter layer on the forest floor. Spruce advance regeneration density is negatively correlated with dominance

Table 3 Variables selected by regression analysis of overstory, undertory, and site variables on spruce and fir advance growth density for Northern New Brunswick. Dependent variables are the count of regeneration species in a 5-m^2 plot. Beta is the standardized regression coefficient; its absolute value indicates its relative contribution to the dependent variable. Both regressions are statistically significant; for balsam fir, $r^2 = .39$, F = 21.85, significance of F = 0.0, S.E. = .47; for spruce, $r^2 = .44$, F = 50.66, significance of F = 0.0, S.E. = .38.

Dependent Variable: Balsam fir advance growth density (Log-transformed).

Independent Variables: Variable		**Beta**	**T**	**Significance of T**
BA5	Basal area of fir	.3734	7.697	.0000
BAIH	Basal area of poplar and white birch	.2312	5.085	.0000
SWUDENS	Density of softwood (DBH < 10cm)	-.1989	-4.53	.0000
ERI	Density of ericaceous spp.	-.1797	-3.686	.0003
SQRTBA3	Basal area of red spruce (square root transformed)	.1653	3.344	.0009
FER	Thickness of the F layer	.1344	2.684	.0076
HAZ	Density of beaked hazel	-.1238	-2.788	.0056
SPH	Percent cover of sphagnum moss	-.1206	-2.653	.0084
STM	Density of striped maple	-.1175	-2.635	.0088
BA13	Basal area of sugar maple	-.09841	-2.181	.0299

Dependant Variable: Spruce advance growth density (Log-transformed).

Independant Variables: Variable		**Beta**	**T**	**Significance of T**
RBASPR	Relative basal area of spruce spp.	.6100	10.290	.0000
BABS	Basal area of black spruce	-.3590	-6.276	.0000
MOS	Percent cover of mosses	.2009	4.199	.0000
BA2	Basal area of white spruce	-.1925	-4.410	.0000
LIT	Depth of the litter layer	.1742	3.736	.0002
ALD	Density of alder	-.1232	-2.929	.0036

of black spruce or white spruce in the overstory. Therefore, spruce advance regeneration density is most abundant in stands with significant red spruce in the overstory. Red spruce is the most shade-tolerant of the three species, and advance regeneration establishment is a characteristic of shade-tolerant species. Presence of alder apparently reduces the likelihood of spruce advance regeneration.

Predicted spruce and fir advance regeneration density for the original site classification plots is compared to actual density by VT in Figures 7 and 8. The VTs that were predicted to show the highest and lowest balsam fir regeneration density did in fact show this relationship (VTs 7 and 3 respectively). The Duncan multiple range procedure tested the null hypothesis of no difference between VTs in balsam fir den-

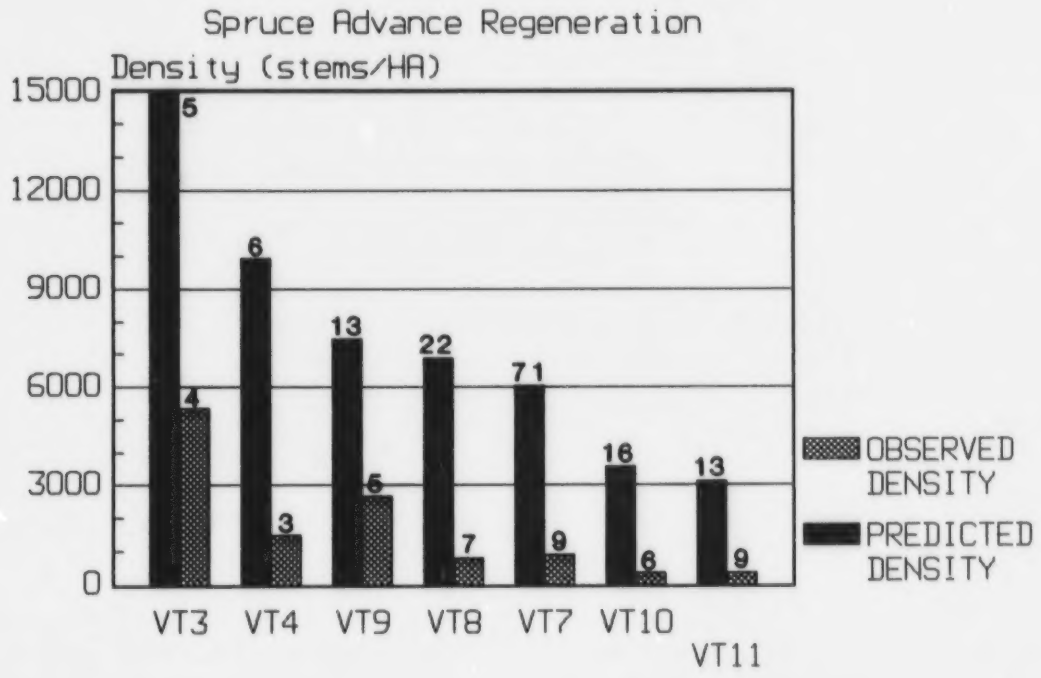


Figure 7 Predicted and observed spruce advance regeneration density. Predictions were derived using regression equations of stand and understory vegetation variables on regeneration density. Numbers above bars denote number of samples.

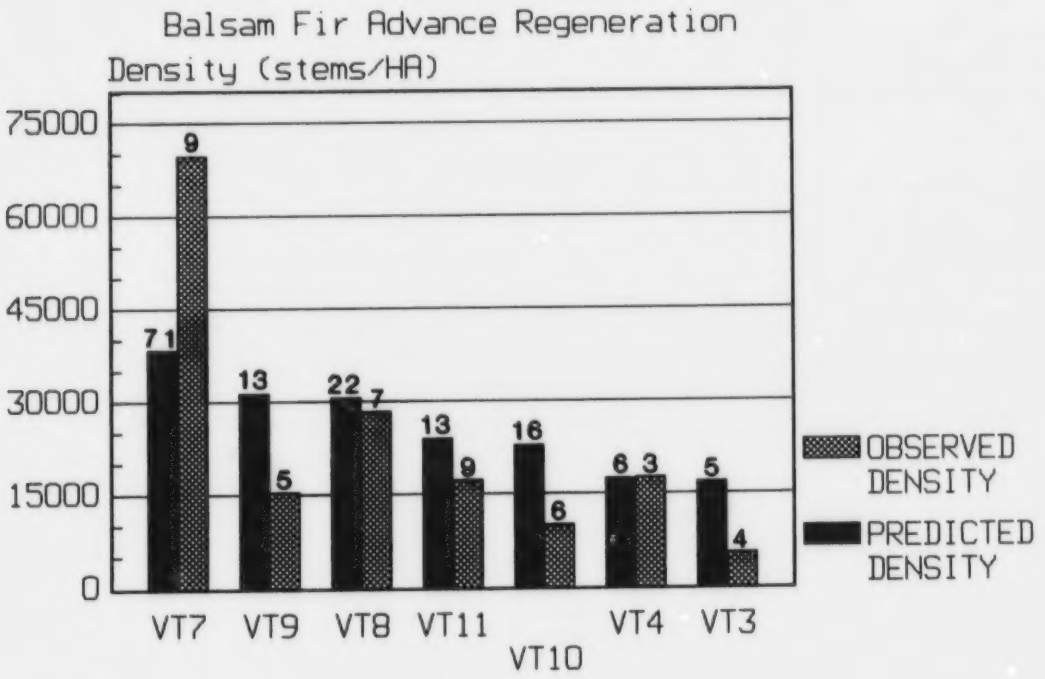


Figure 8 Predicted and observed balsam fir advance regeneration density. Predictions were derived using regression equations of stand and understory vegetation variables on regeneration density. Numbers above bars denote number of samples.

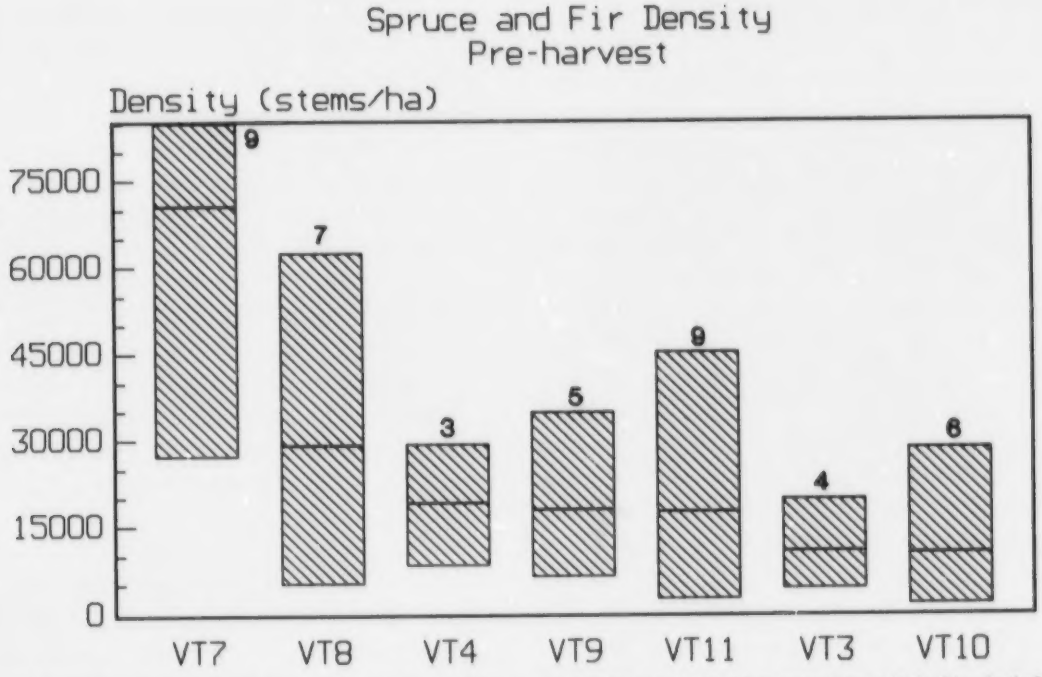


Figure 9 Mean and range of preharvest advance regeneration spruce and fir density for Vegetation Types in the Upsalquitch site region. Upper range for VT7 is 170000. Numbers in plot denote sample size.

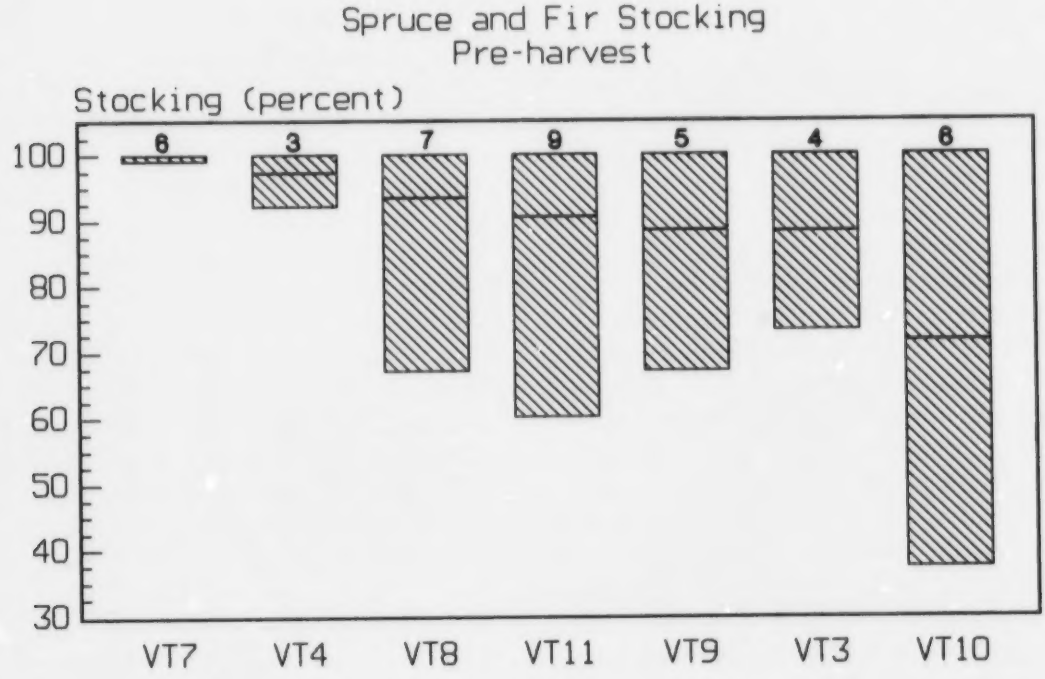


Figure 10 Mean and range of spruce and fir stocking preharvest by Vegetation Type in the Upsalquitch site region. Numbers above bars denote sample size.

sity. VT7 shows significantly higher density than the other groups ($P < 0.05$). Although predicted spruce density was far greater than observed for all VTs, the ranking of VTs from highest predicted density to lowest is close to what was observed. Again using the Duncan procedure, VT3 was shown to possess greater spruce advance regeneration density than other VTs ($P < 0.05$). VT9 also has greater density of spruce than VT10 or VT11 ($P < 0.05$).

Mean total spruce and fir advance regeneration density and stocking are shown in Figures 9 and 10. VT7 has significantly higher density than other VTs ($P < 0.05$), but there are no significant differences among the rest. VT10 has a significantly lower stocking level than VTs 11, 8, 4, and 7. Variability observed within VTs (Figure 9) is high. High variability and a lack of significant differences between VTs raise some doubt about the usefulness of VTs as defined to predict advance regeneration abundance.

DISCUSSION

There is a perception among many users of site classification (even prevalent among specialists) that it is the nature of an "ecological" site classification to be "holistic", or interpretable for a wide array of land uses. However, this is only true to the extent that the classification tool uses variables that are influential upon the intended interpretation. Despite the "ecological" nature of the N.B. Site Classification, there is high advance regeneration variability within groups (in this case VTs), which were defined with the intent of maximizing their distinctiveness in terms of productivity of spruce, fir, or jack pine. Therefore, the "optimal" subdivision of the total range of ecological conditions may not be the same for the productivity interpretation as it is for the natural regeneration interpretation (see Jones 1987).

Recall that in constructing the Vegetation Type Key we utilized species presence and absence whenever possible rather than measures of abundance or stand density to define the units. However, the regression analysis identified a number of important variables that clearly are measures of abundance (Table 3).

The Decorana ordination for the Upsalquitch Site Region (Figure 6) is a representation of the position of each sample stand across the range of ecological conditions existing there. The position of each plot is determined by algorithms that consider species abundance and presence/absence. Predicted advance regeneration density is shown in the context of the Decorana ordination of the Upsalquitch Site Region in Figures 11 and 12. It is apparent that there are trends of advance regeneration abundance relative to position on the ordination. However, there is considerable variability in predicted spruce and fir advance regeneration densities within VTs. Figure 13 shows a detail of the upper-right portion of Figure 11. Plots belonging to VT11 are, generally, on the left side of the ordination, and plots of VT12 are for the most part on the right. Interestingly, those VT11 plots that are on the right have lower predicted advance regeneration density than the "average" VT11 plot. The converse is true for VT12 plots; those on the left are more likely to have greater advance regeneration densities. In view of this discrepancy, the vegetation classification scheme that better captures the difference between plots on the left and the right is the one we need to interpret advance regeneration abundance. It will likely utilize measures of abundance of critical overstory species to a greater extent than the productivity-oriented Vegetation Type classification does.

Therefore, additions to the Vegetation Type classification are needed to help reduce within-VT variability in advance regeneration abundance.

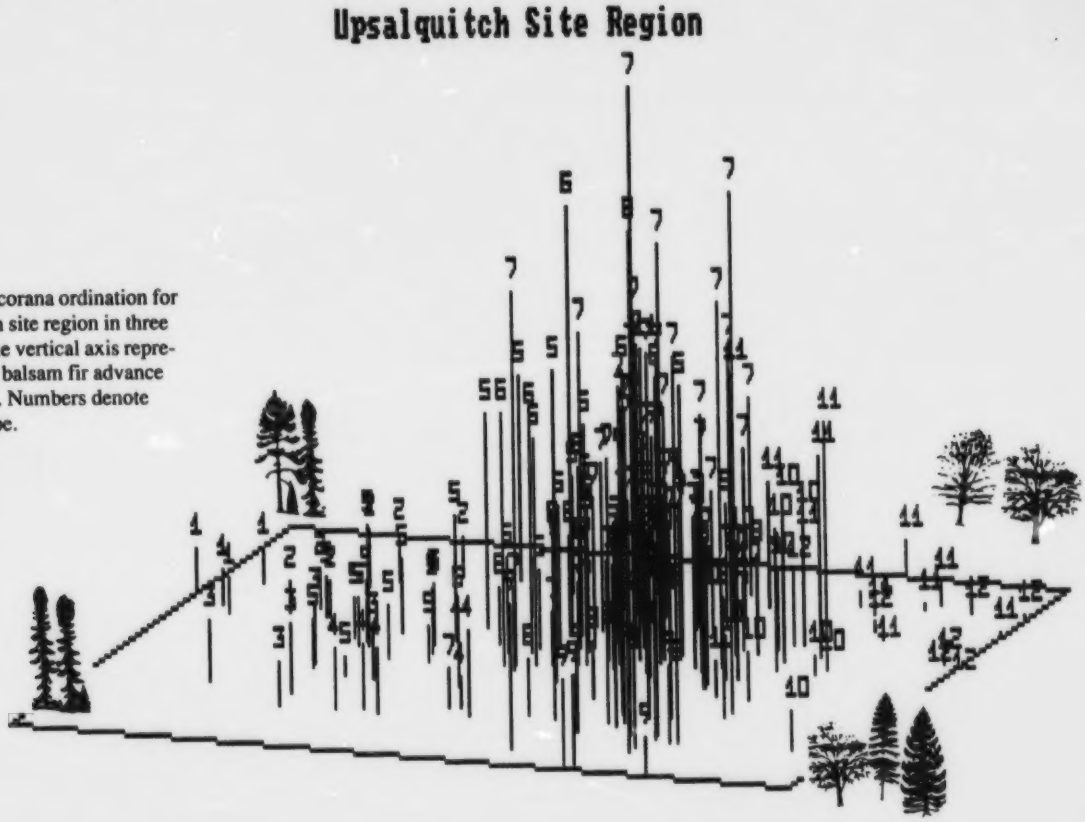


Figure 11 Decorana ordination for the Upsalquitch site region in three dimensions. The vertical axis represents predicted balsam fir advance growth density. Numbers denote Vegetation Type.

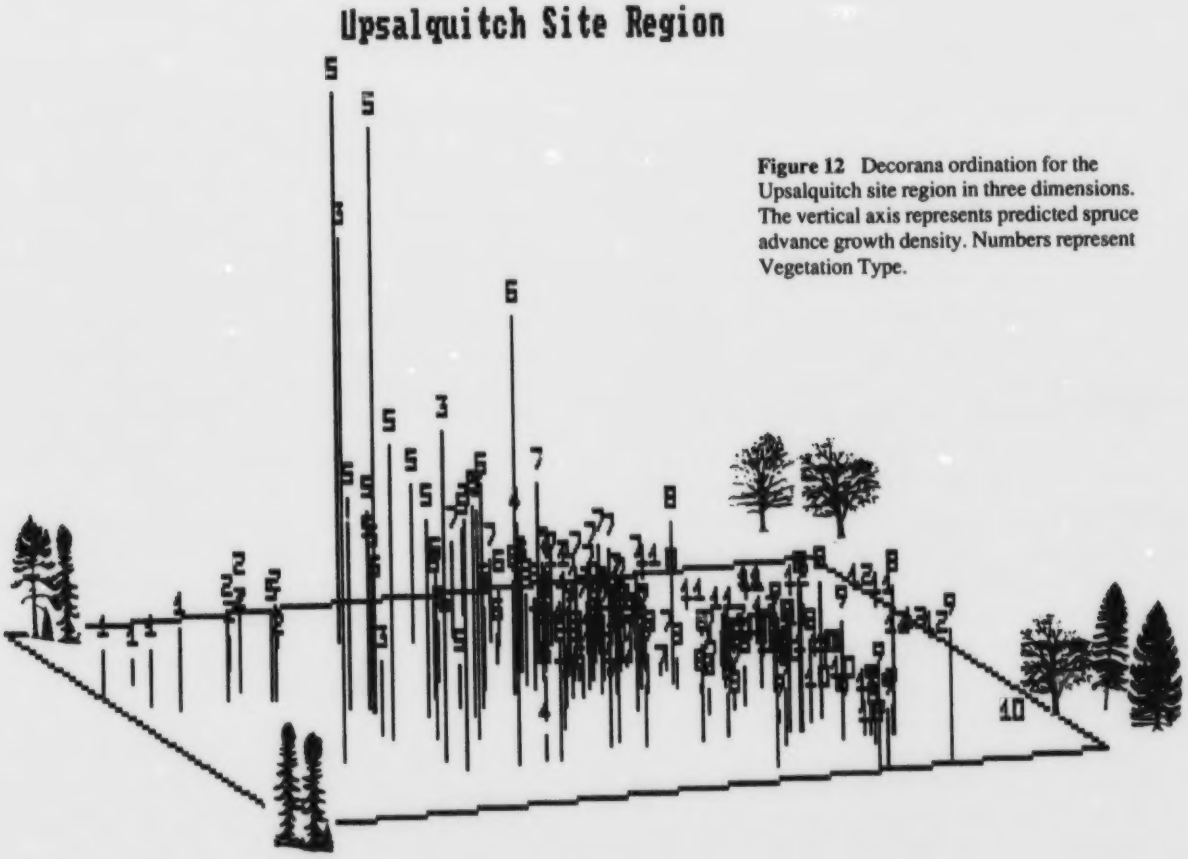


Figure 12 Decorana ordination for the Upsalquitch site region in three dimensions. The vertical axis represents predicted spruce advance growth density. Numbers represent Vegetation Type.

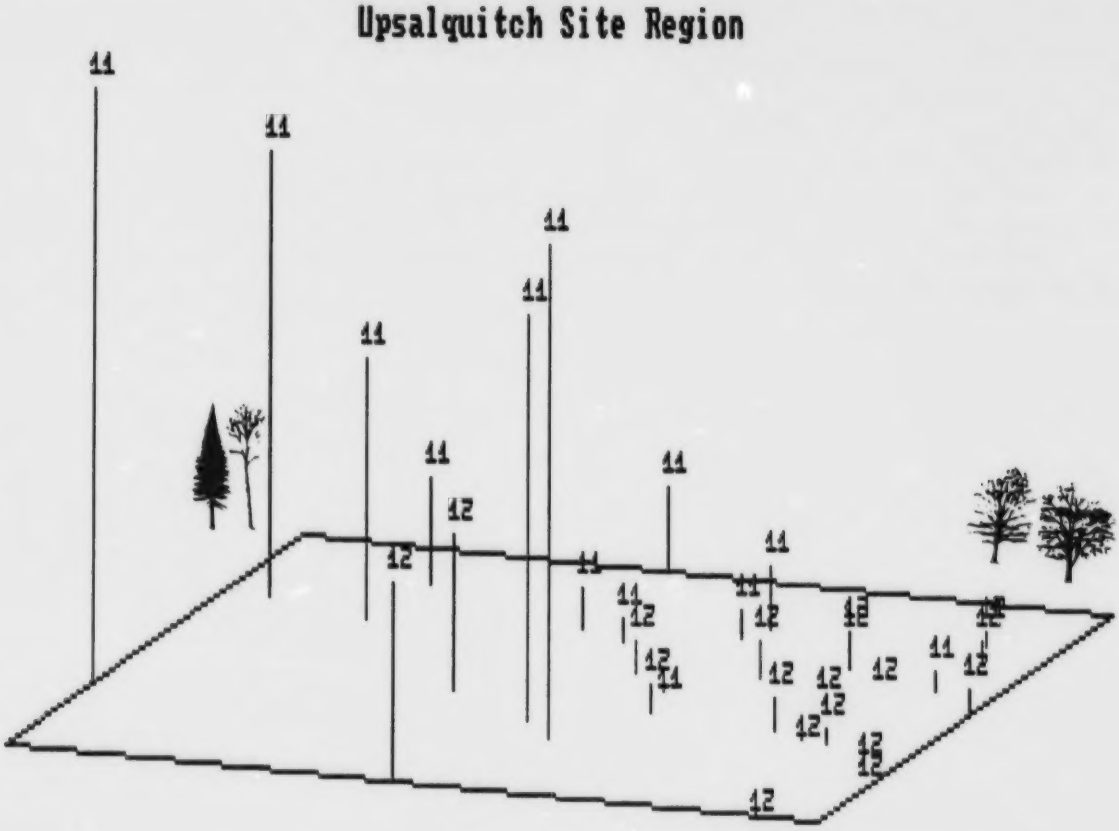


Figure 13 Decorana ordination in three dimensions. The vertical axis represents balsam fir advance growth density. Numbers in the plot denote Vegetation Type (detail of the upper-right portion of the ordination in Figure 10).

Management Context

In future, all areas to be silviculturally treated will require site classification. We now possess the capability to produce large-scale site classification maps. The site classification will be an estimation based on soil mapping (1:50,000 scale) to estimate STs, and VT mapping estimated using algorithms that link forest inventory maps (1:12,500) with VTs. Using GIS technology it becomes a simple exercise to produce TU maps by merging the two layers.

Under one possible scenario, potential treatment areas could be ranked on the basis of site quality as determined from TU maps. These "best choices" can be field-checked to determine the actual TU.

By linking advance regeneration species and abundance to existing maps, we will provide a means to assess the probable abundance of natural spruce and fir regeneration in pre-harvest stands. The likelihood of achieving adequate stocking postharvest depends to a large extent on the preharvest abundance of natural regeneration. If we succeed in displaying this information with reasonable accuracy on maps, forest managers will be in a better position to judge well ahead of time what areas will give the best yield if treated, whether they will have to plant to achieve satisfactory stocking, or whether a precommercial thinning chance will exist. With the lead-time provided they will have the option of performing ground checks, and allocating harvesting systems and/or site preparation to help them achieve their regeneration objectives.

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VARIATIONS IN THE ABUNDANCE OF ADVANCED FIR REGENERATION IN THE PRINCIPAL FIR ECOLOGICAL TYPES OF THE BALSAM FIR-WHITE BIRCH DOMAIN IN CENTRAL QUEBEC

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INTRODUCTION

Until recently, foresters in Quebec have generally accepted as a fact the proposal that boreal balsam fir (*Abies balsamea*) stands did not pose a regeneration problem if advanced regeneration was protected (Crcha *et al.* 1983). This assertion was based on several studies undertaken during the 1950s and '60s in different parts of the province, all of which showed very satisfactory regeneration levels after clearcutting (Smithers 1948; Hatcher 1960; Webb 1961; McArthur 1963). In fact, the perceived regeneration problem was that of an overabundance of balsam fir regeneration, which could cause severe growth stagnation (Vézina 1971).

This is what was observed at Forêt Montmorency, the research forest of Laval University situated 70 km north of Quebec City (Figure 1). This forest, which is typical of the balsam fir-white birch (*Betula papyrifera*) ecological domain, was harvested in the 1940s. More than 90% of the second growth stands have remained pure fir.

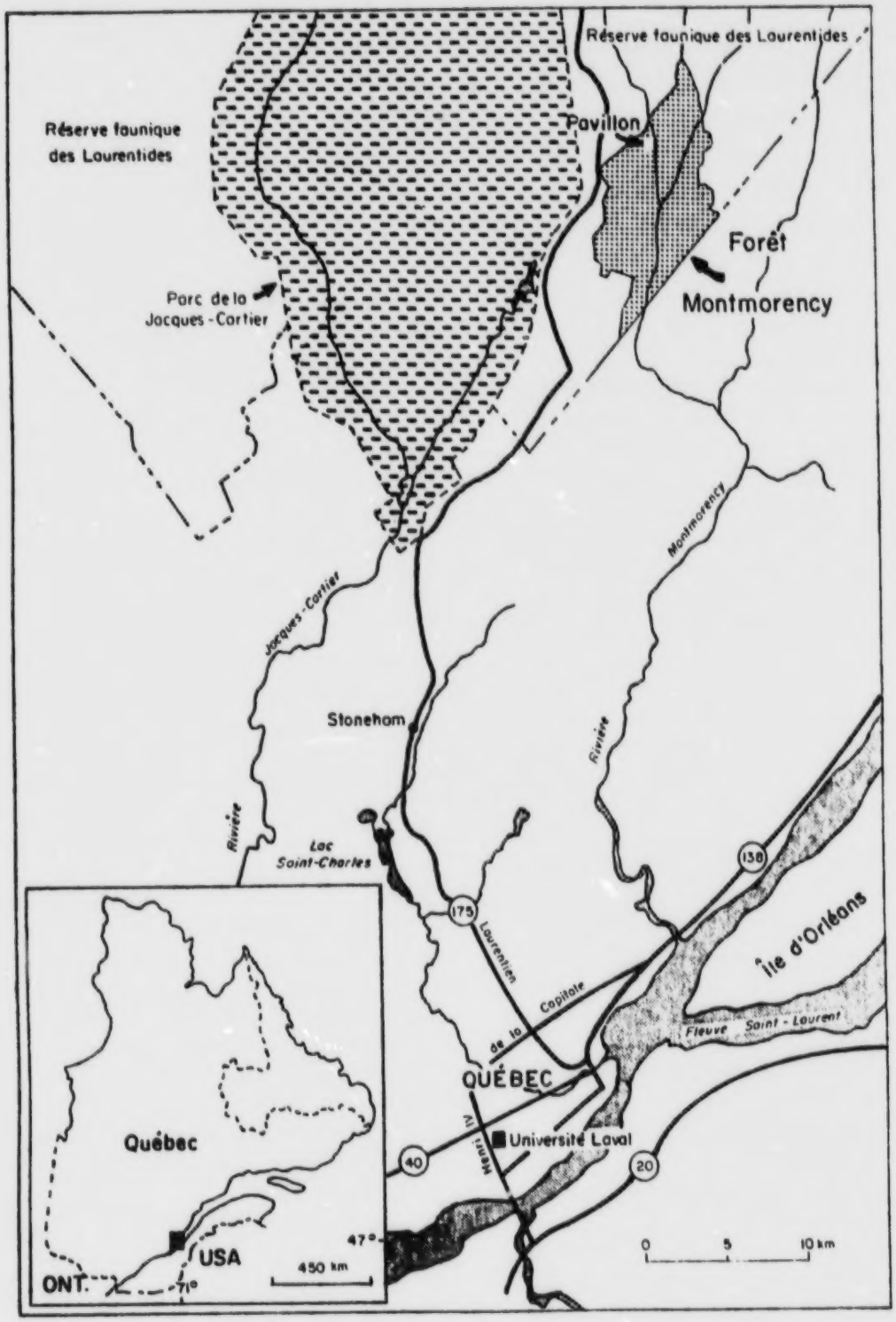
On this basis, the regeneration strategy adopted for more than 25 years at Forêt Montmorency was to systematically protect advanced regeneration by using a semi-manual harvesting method using a F-4-Dion forwarder. Such a strategy was implicitly based on the assumption that natural regeneration success obtained in the virgin fir stands could also be achieved in the mature second growth fir stands.

Unfortunately, this has not proven correct. Important softwood regeneration failures can be observed at Forêt Montmorency in spite of all the care taken in this experimental forest. Left on their own, important sectors are now converting to white birch. But what is also surprising is the large variation in regeneration success while harvesting at approximately the same rotation age of 60 years and using the same harvesting method. As indicated in Table 1, half the cut blocks harvested over the last 15 years are not sufficiently regenerated, *i.e.*, have stocking levels of less than 60%, while in the other half, more than sufficient fir regeneration can be found.

One possible cause for these wide variations in otherwise similar conditions, could be due to significant differences in the abundance of advanced regeneration between the balsam fir ecological types. To test this hypothesis, two studies were conducted to compare the stocking and density levels of softwood advanced regeneration present under the principal balsam fir ecological types of the balsam fir-white birch domain in central Quebec (Côté 1989; Marchand 1990).

ADVANCED REGENERATION ABUNDANCE IN FORÊT MONTMORENCY

Our first study was conducted in Forêt Montmorency. Results presented here are those that come from second growth pure fir stands 45 to 50 years old. These correspond to mature stands according to the new rotation ages now in use in Quebec for this type of boreal forest (Boudoux 1978).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Réserve faunique des Laurentides
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Figure 1

Table 1 Natural regeneration success after harvesting at Forêt Montmorency (1975-1988)

Success Class	Softwood Regeneration Abundance Stocking Level (%)	Proportion of Harvested Area (%)
Insufficient	0-40	18
Marginal	41-60	30
Sufficient	61-80	32
Satisfactory	81-100	20

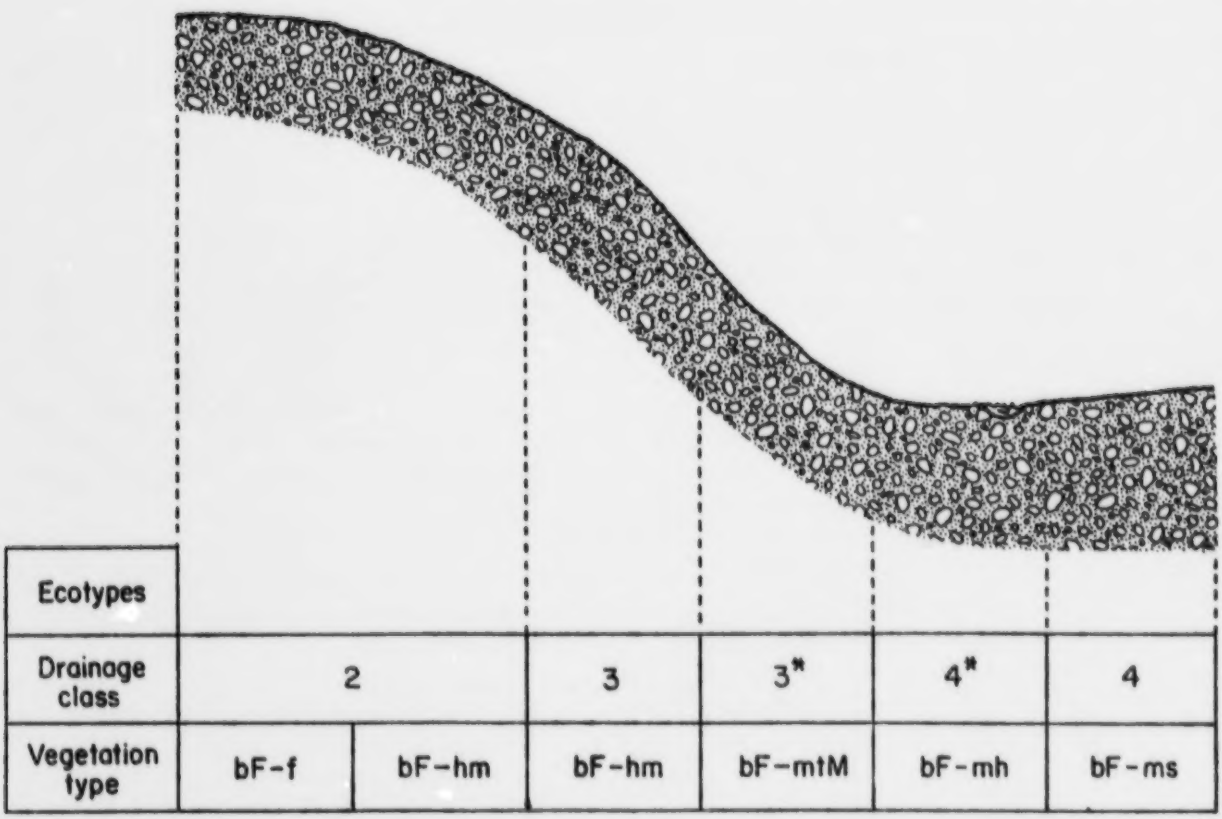


Figure 2 Principal fir ecological types of the balsam fir-white birch ecological domain at ForêtMontmorency, Quebec

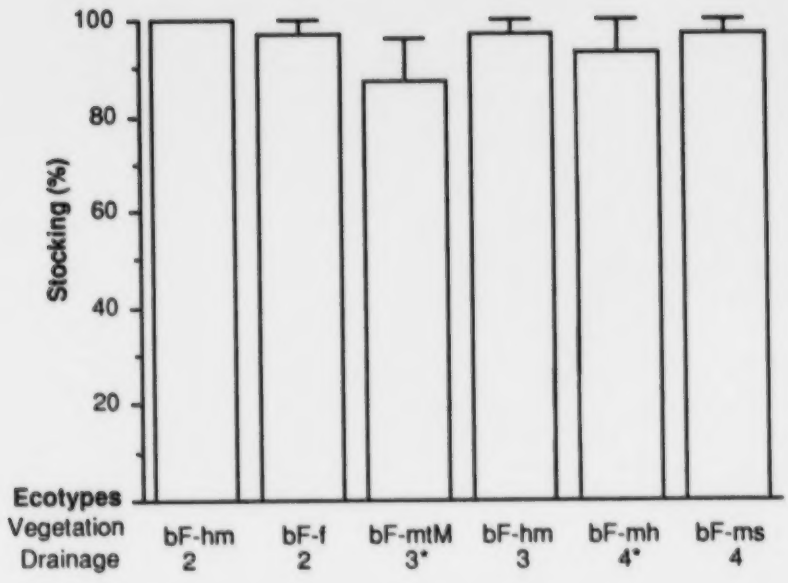


Figure 3 Stocking levels of balsam fir advanced regeneration in Forêt Montmorency

MATERIALS AND METHODS

Six ecological types were sampled. These ecotypes are distributed essentially according to a moisture gradient (Figure 2). Important differences in ground vegetation can be observed following this moisture gradient. The six ecological types were:

1. the balsam fir-fern type on well drained tills,
2. the balsam fir-herb and moss type on well drained tills,
3. the same balsam fir-herb and moss type, but on moderately drained tills,
4. the balsam fir-mountain maple type on moderately drained tills with seepage,
5. the balsam fir-moss and herb type on imperfectly drained tills with seepage, and
6. the balsam fir-moss and sphagnum type on imperfectly drained tills.

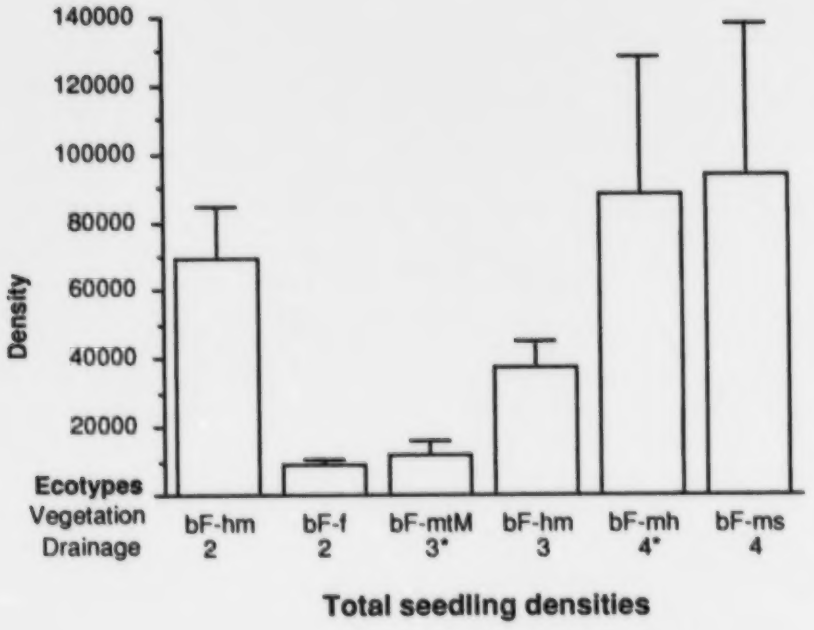
The basal area of the sampled stands varied between 40 and 50 m^2/ha with a canopy cover of 80 to 85%. These stands had been somewhat affected by the last spruce budworm outbreak between 1975 and 1985, but were systematically protected with insecticide sprayings.

RESULTS

General results

Balsam fir formed almost all of the softwood advanced regeneration, white and black spruce represented less than 2% of the total. A bit surprisingly, the survey did not indicate any significant difference in the stocking levels of fir advanced regeneration between ecotypes (Figure 3). On all sites, stocking was over 90%. This is well above the 75% stocking level requirement suggested in Quebec as sufficient to ensure successful natural regeneration (MER 1989).

However, this picture is considerably different when the density levels are compared. Indeed, very important differences exist between ecotypes (Figure 4). Total seedling densities varied from less than 10 000 seedlings/ha on the rich mesic types, to more than 90 000 seedlings/ha on the humid types. The same differences remain when the older seedlings of more than 5 cm in height are



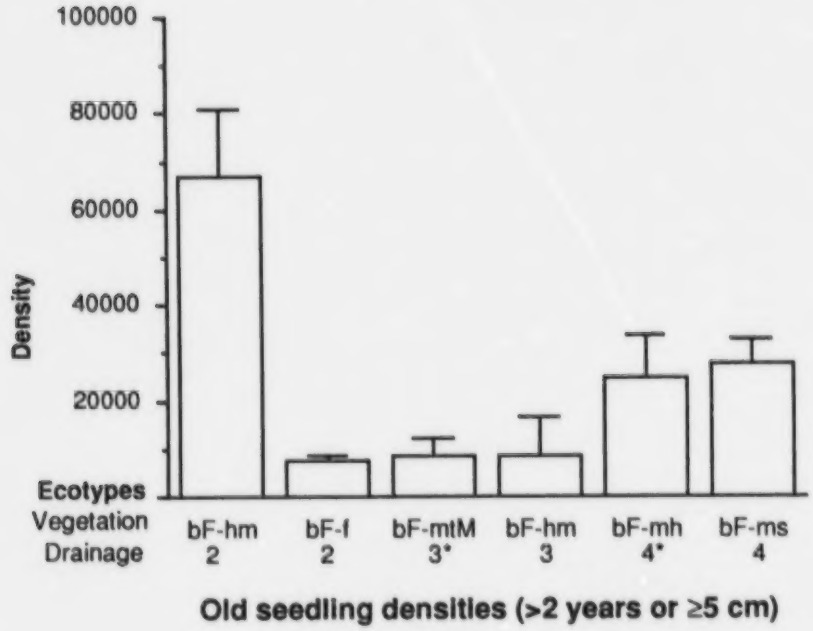


Figure 4 Balsam fir seedling densities following fir ecological types in Forêt Montmorency

Table 2 Fir seedling density classes

Class	Density Range (seedlings/ha)	Ecological Type
Low density types	<15 000	bF-f, 2 bF-mtM, 3*
High density types	25 000-40 000	bF-hm, 3 bF-mh, 4* bF-ms, 4
Very high density types	>60 000	bF-hm, 2

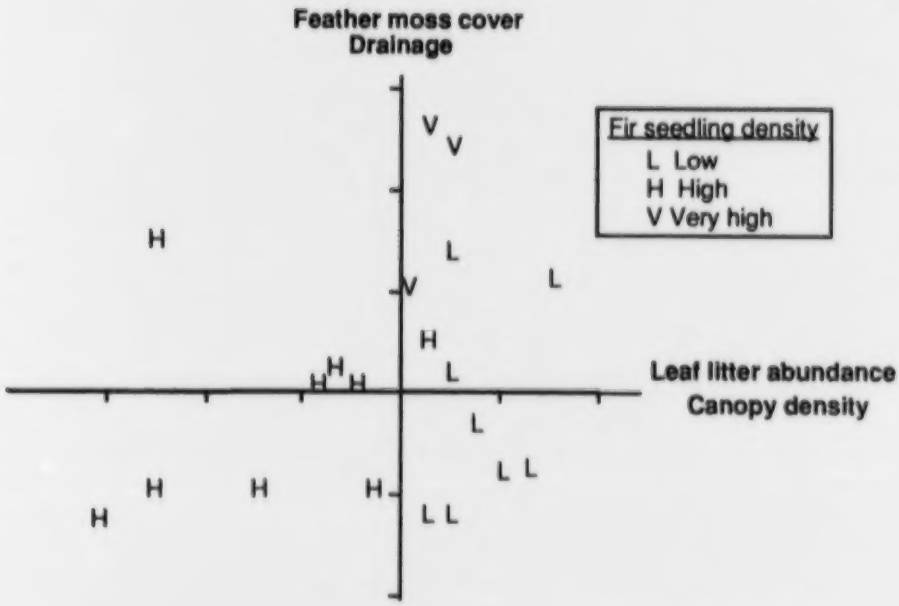


Figure 5 Discriminant analysis following fir (>2 years) advanced regeneration abundance

considered. It is interesting to note the important differences between the two fir types situated on the same dry sites but which differ in their ground vegetation characteristics.

Cluster analysis

The Scott-Knott procedure (Scott and Knott 1974), is a clustering method for grouping means after an analysis of variance, was used to define distinct categories following the abundance of fir regeneration.

Three groups could be distinguished (Table 2). The low seedling density group, with seedling densities of less than 15 000/ha, includes the two fir ecotypes with an important herb layer. These types are also known to be the most productive. They are found on well drained tills as well as on moderately drained tills with seepage. The high density class regroups three ecological types with seedling densities of approximately 30 000 to 40 000/ha. Finally, the very high seedling density class is formed by the balsam fir-herb moss type on dry sites.

Discriminant analysis

To link these results with specific ecological and stand characteristics, a discriminant analysis was undertaken. The objective was to identify certain key indicator factors that could help predict advanced regeneration abundance.

The best model found retained only four variables (Figure 5). These are:

1. cover of broadleaf litter,
2. cover of feather mosses,
3. canopy density, and
4. drainage.

On the first axis, low seedling density stands are clearly seperated from high seedling density stands. These low density stands are distinguished by their more important broadleaf litter cover as well as by a higher canopy cover. The second discriminant axis separates more specifically the very high seedling density stands. These stands are distinguished from the low density stands by a higher feather moss cover and by their better drainage.

ADVANCED REGENERATION ABUNDANCE IN PARC DE LA JACQUES-CARTIER

This first study was made with a relatively small sample. To validate the results and verify their predictive value, on a larger sample size, a second study was initiated in similar stands situated in areas that had not been protected during the spruce budworm outbreak. The effect of the budworm outbreak on the abundance of regeneration was also checked.

MATERIALS AND METHODS

The second study was conducted in the Parc de la Jacques-Cartier for two ecotypes representative of the previous seedling density classes. These are the balsam fir-mountain maple type on moderately well drained sites with seepage and the balsam fir-herb and moss type on moderately well drained sites. In each of these ecotypes, six sample plots were surveyed. Species, age, and height of every seedling were noted on ten 4-m^2 plots.

RESULTS

Density and stocking

Balsam fir seedling densities measured in Parc de la Jacques-Cartier tend to confirm the conclusion of the first study: the two ecotypes differ significantly from one another (Figure 6). The average seedling density under the balsam fir-herb and moss type was twice the amount under the balsam fir-mountain maple type, *i.e.*, 63 000 seedlings/ha compared to 28000/ha. However, even if seedling densities are very different, the average stocking on

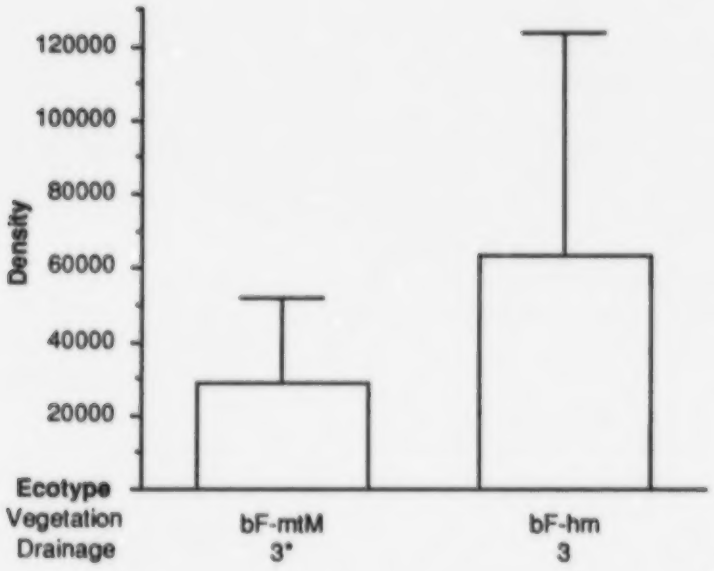
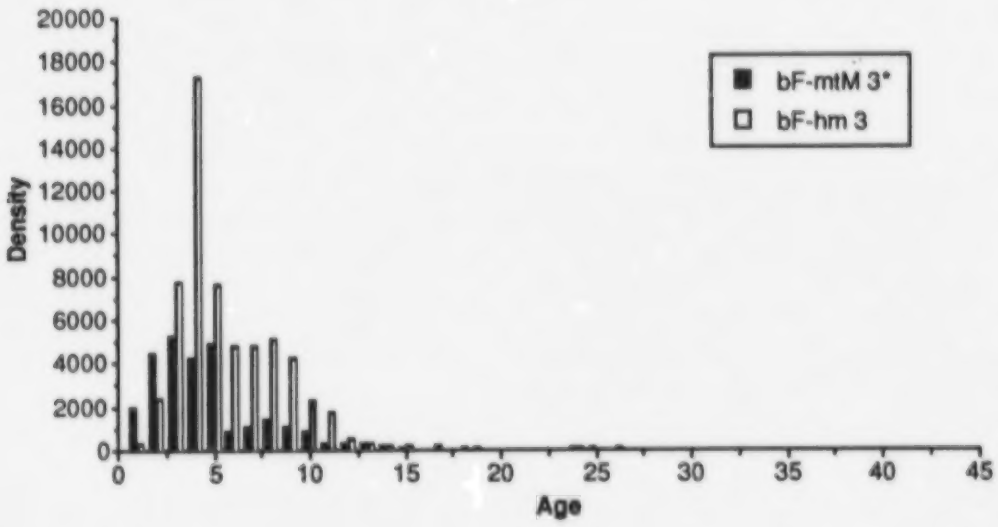


Figure 6 Balsam fir seedling densities in Parc de la Jacques-Cartier



Age class	0-6	7-10	11-20	>20	Total
bF-hm 3	42155 (67%)	17102 (27%)	3282 (5%)	567 (1%)	63106
bF-mtM 3*	21635 (76%)	4567 (16%)	1798 (6%)	542 (2%)	28542

Figure 7 Age structure of balsam fir advanced regeneration in Parc de la Jacques-Cartier

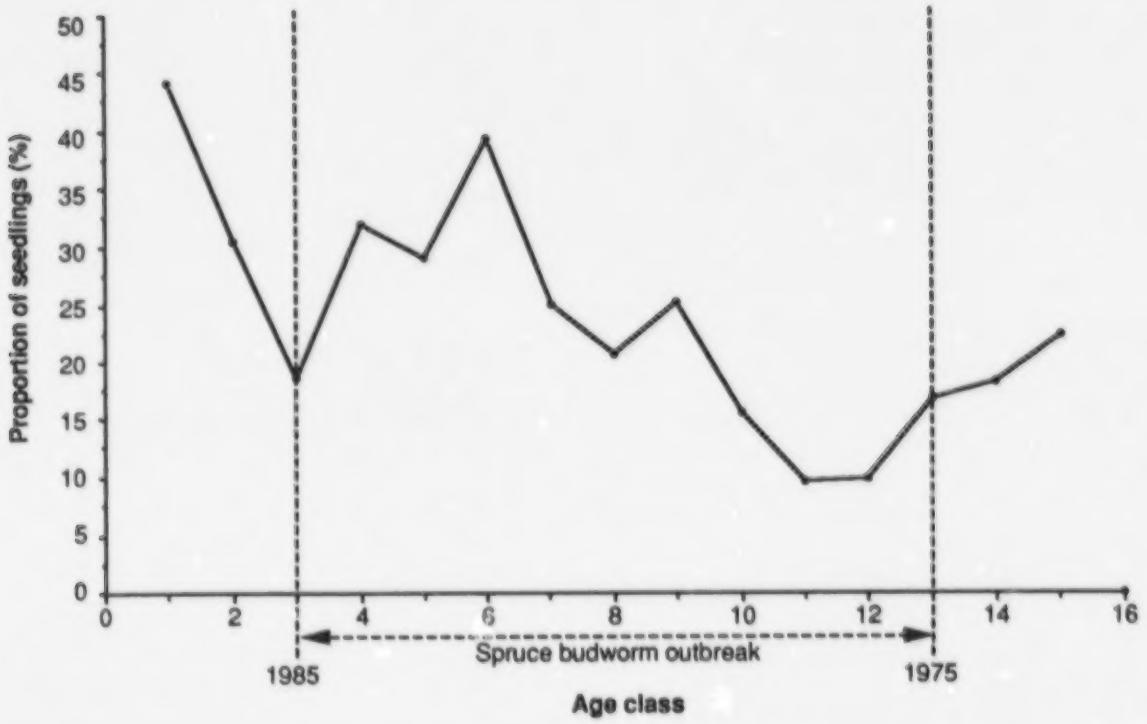


Figure 8 Proportion of balsam fir seedlings established in the balsam fir-mountain maple type compared to the balsam fir-herb and moss type

both ecotypes was higher than 80% and showed differences of less than 10%.

Age and height

As to their age characteristics, fir seedlings in both ecotypes were relatively young. The older seedlings were less than 20 years old (Figure 7). This is not surprising, considering that stands were 50 years old and regular seed production for fir begins 30 years after release. Most of the seedlings were less than 6 years old. This means that 65% of the seedlings were still at the juvenile stage, where height growth is restricted whatever the light intensity (Logan 1969). If seedlings at this growth were not composted, density in the balsam fir-herb and moss type would be 21 000 seedlings/ha compared to only 7 000 seedlings/ha for the balsam fir-mountain maple type.

This is reflected by the height characteristics of the seedlings. More than 50% of the seedlings were smaller than 10 cm in both ecotypes.

Possible processes involved

Two processes could possibly explain the important differences in abundance observed between the different fir ecotypes.

- On one hand, ecotypes could vary in their seed production, especially in the context of the budworm outbreak.

- On the other hand, the establishment and survival rates of young fir regeneration could differ between sites due to different seedbed conditions.

Effect of the spruce budworm outbreak

The possible effect of the spruce budworm outbreak should be reflected in the age structure of the advanced regeneration. However,

Table 3 Seedbed suitability for fir advanced regeneration

Suitability Class	Seedbed Type	% Seedbed Cover	% of Seedlings
Favorable	Conifer needle litter	17	20
	Mixed needle-leaf litter	25	29
Neutral	Feather mosses	27	26
	Mosses on dead wood	14	15
	Mosses on rocks	11	9
Unfavorable	Leaf litter	28	16
	Sphagnum	22	12

even if the density levels in the two types are considerably different, the relative age distribution of each population is very similar. Furthermore, the proportion of seedlings of a given age in one ecotype compared to the number of seedlings of the same age in the other ecotype, remained relatively constant during the outbreak (Figure 8). Therefore, if the spruce budworm had an impact on seed production, the effect was similar for the two ecotypes. On this basis, the seed production hypothesis does not seem to explain the differences in abundance between the two types.

Seedbed suitability

As for the seedbed suitability hypothesis, several researchers have shown the influence of seedbed conditions on the establishment rate of fir regeneration (Place 1955; Fye and Thomas 1963). To check if seedbed conditions could partly explain differences in the abundance of fir regeneration, seedbed suitability was determined on an empirical basis.

This was done by comparing the proportion of seedbed conditions available in a particular stand with the proportion of seedlings effectively found on each seedbed condition. The hypothesis was that, if a certain type of seedbed was unfavorable to fir establishment, the proportion of seedlings found on that type would be less than the porportion of that seedbed type available in the stand.

On this basis, three suitability classes were determined (Table 3).

- Conifer needle litter, as well as mixed needle-leaf litter, is somewhat favorable to fir establishment.

- Mosses, mosses on decomposed wood, and mosses on rocks are neutral seedbed conditions, the proportion of seedlings found on each type being equivalent to the cover of each one.

- Finally, two seedbed types seem to be unfavorable to fir establishment and survival. These are the leaf litter type and the sphagnum type.

These results then seem to confirm the discriminant analysis and point to the importance of seedbed conditions on the abundance of fir advanced regeneration. They also fit perfectly with seedbed conditions noted for the other fir ecotypes.

CONCLUSION

In conclusion, results obtained during our study of advanced regeneration in second growth fir stands point to certain conclusions:

1. Second growth balsam fir ecotypes vary significantly as to the abundance of advanced fir regeneration.

2. Natural regeneration problems can be anticipated in certain of these ecotypes if harvested at the age of 45 to 50 years.

3. On an empirical basis, seedbed conditions seem to play an important role in the abundance of advanced regeneration. Ecotypes characterized by abundant leaflitter seedbeds (the most productive sites) are those with the least regeneration.

4. It is possible to locate these sites using ecological forest maps such as those presently being developed by the Ministère de l'Énergie et des Ressources in Québec.

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PREDICTION OF ADVANCED REGENERATION: A QUEBEC EXPERIENCE

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ABSTRACT

The prediction of advanced regeneration in precut stands is an operational concern of the Saguenay Division of Stone-Consolidated. To quantify postcut regeneration response, an inventory was performed on company cutovers dating since 1980. Advanced growth is generally abundant in softwood stands and maintenance of forest cover is not problematic. Improved preservation of advanced growth by adapting harvest methods has been implemented in the Division since 1987. The importance of natural regeneration for future yield and sustainable wood supply highlights the need to improve predictive tools. Precut regeneration assessments are currently undertaken to better understand cutover response.

INTRODUCTION

Predicting advanced regeneration in precut stands is an operational concern of Stone-Consolidated. Productivity- oriented site classification techniques and corresponding future yield expectations are not readily available to industry users at large for predicting softwood advanced regeneration in mature and overmature stands. Several approaches are under study, as highlighted by other conference speakers. I would like to put forward an operator's perspective and indicate what steps have been undertaken by our Saguenay Division within the context of Quebec's forest policy . The Quebec experience, as indicated in the title, is that of one operator, Stone, in the Saguenay Lac St-Jean Region.

BACKGROUND

Stone-Consolidated's Saguenay Division is one of three Woodlands Divisions operating in the province of Quebec. The Division supplies 1.5 million m^3 of wood fiber to a newsprint mill in La Baie and four sawmills in the Saguenay Lac St-Jean region. Operating in the boreal forest region, the company procures wood from the area around Lac Poulin-Courval, Lac Pribonka, Chibougamau, and south of Lac St-Jean.

Ecological regions covered by company forest management agreements include the black spruce region of the Pribonka and Chibougamau Districts, and the fir-white birch and fir-spruce regions of Roberval and Portneuf/Escoumins Districts (Thibeault, 1985).

The Division is in the process of negotiating forest management agreements with the Province, known as "Contrats d'approvisionnement et d'aménagement forestier" (CAAF). These agreements specify allowable cutting limits with silvicultural levels to maintain and requirements to produce annual, 5-, and 25-year operating plans.

In 1987, the Quebec Government passed a new forest policy, Bill 150. The five major points under which responsibility is shared between companies and the government are:

- the Ministère de l'énergie et des ressources (MER) fixes sustainable wood supply objectives and ensures the realisation of sylvicultural programs;

- forest companies plan interventions and execute forest management plans;

- forest companies ensure maintenance of forest cover;

- MER performs work to put into production areas poorly regenerated that were cut before April 1st 1987.

- MER ensures production of plants necessary for planting programs.

There are three main documents in which MER defines specifically how intervention is to be carried out on public lands.

Le Guide des Modalités d'Intervention defines the delimitation of public lands for multiple use, with the objectives of protecting water quality and recreational sites, ensuring habitat protection for wildlife, and ensuring adequate forest renewal.

The **Management Manual** defines the relationship between MER and CAAF holders. It defines the method of wood supply calculation and silviculture treatments admissible for payment with their evaluation criterion.

The **Management Agreement** is a 25-year contract which defines the forested lands upon which the volume agreement exists, with a description of forest classes and forest development assumptions.

A part of industry's obligation under Bill 150 is to ensure that forest cover is maintained. Adequate renewal of harvested stands is a requirement and, where insufficient stocking exists, artifical regeneration is prescribed.

The standards that must be met for regeneration mean that, 2 years after treatment, a stocking of principal species equal to or greater than the stocking of the original stand should be in place. Eight years after, the stocking must be considered to be in a free-to-grow status.

REGENERATION INVENTORY

In order to better develop forest management strategies, the company undertook an survey of lands cut since 1980 to determine the condition of regeneration on our license (Dryade, 1987). The survey consisted of the following eight questions:

1. Are the cuts well regenerated?

2. Are there some sites that regenerate better? If so, which? Is forest cover maintained?

3. Is the composition of the regeneration the same on all sites?

4. What is the condition of the competition on the softwood regeneration?

5. How is the vegetation evolving in the years following cutting?

6. Are differences noted between the different cutting methods employed on the regeneration?

7. What must be done or looked at over the coming years in order to encourage development of adequate regeneration?

8. What type of forets will eventually develop on the recent cutovers (strate de retour)?

Interpretation of surfical deposit and drainage was carried out on aerial photos at a scale of 1:15840 upon which topographic contours had been delimited. The dominant geomorphologic type was interpreted within each forest stand. The information was then transferred to maps, with cutblocks indicating year cut and method.

The survey consisted of approximately 80 regeneration plots per sampling unit (homogeneous area defined as a function of year cut, method of cut, and geomorphologic type) which corresponded to a precision search of 90% for stocking of a sampling unit. All inventory data were collected with portable data collectors. Each factor was sampled.

Data collected were year and method cut,slash cover, surface drainage, surface deposit, humus depth, ecological region (Thibeault 1985), stump height, forest unit, regeneration species, quality, height classes, and competition factors.

Results of this survey have given us a better understanding the regeneration patterns on our forest license. To summarize our observations, it was noted that maintenance of forest cover is not considered a problem. Most forest units had softwood stocking ranging from 76% to 90% after cutting. Stocking on well drained sandy soils had the least postcut stocking at 42%, composed principally of layered spruce and fir. Sites favorable to the development of fir had the most competition problem, primarily white birch. Softwood regeneration was, for the most part, present before cutting. Layered spruce occupied a fairly significant portion of regeneration stocking in spruce dominated stands.

These results are similar to those that have been reported in precut stand conditions in the province. Jean-Claude Ruel (Ruel 1987, 1988) highlights the fact that the majority of forest units harvested in Quebec have an abundant advanced regeneration before cut. About three quarters of area harvested had a softwood stocking of 75% or greater. The only forest units which showed an exception were on pine sites and, to a lesser degree, on mixedwood sites. Advanced regeneration in black spruce sites was formed, to a large degree, by layering.

The yield expectation differences from seed-originated black spruce and layered black spruce will be presented by J.-M. Lussier of the Université du Québec, Chicoutimi (Lussier *et al.*, 1991).

An important change in operating method has taken place in the Division since 1987, with the introduction of fully mechanized operations and the application of CPRP.

CPRP

The MER defines CPRP or Coupe avec protection de la régénération préétablie (protection of advanced regeneration) as a sylvicultural treatment admissible towards a reduction in stumpage charge. It is a way of modifying the harvest method to protect regeneration.

The system is applied to conventional as well as mechanized operations. The four principal factors characterizing the conventional system are:

1. Limiting skidder displacement to predetermined skidways.
2. Limiting the number of skidder turnouts.
3. Directional felling.
4. Recuperating maximum amount of stems with the cable.

The four principal factors affecting regeneration protection with mechanical systems are:

1. Displacement of machinery
2. Type of machinery.
3. Forest workers' attitudes.
4. Harvesting strategy.

Table 1 Silvicultural treatments carried out by industry (Traitements sylvicoles réalisés par l'industrie)

Silvicultural Treatment/ Traitement sylvicole	Area (ha)/ Superficie (ha) 1987	1988
Clearcut/Coupe à blanc	195 000	132 000
Strip or group clearcut/Coupe à blanc par bandes/trouées	3 700	5 500
Clearcut with regeneration protection/Coupe avec protection de régénération	52 400	113 800
Harvest on wooded strips/Récolte dans lisières boisées	10 500	8 700
Selection felling/Coupe de jardinage	8 000	17 600
Commercial thinning cut/Coupe d'éclaircie commerciale	0	385
Total harvested/Total-Récolte	269 600	277 985
Precommercial thinning cut/Coupe d'éclaircie pré-commerciale	6 900	10 000
Site preparation/Préparation du terrain	91 245	98 263
Planting/Plantation	54 440	66 300
Seeding/Ensemencement	137	200
Weeding regeneration/Dégagement de régénération	12 100	18 000

Source: Info-forêt, Vol. 1 (5), juin 1989

A system description is detailed in two MER publications (MER 1987, 1989). At Sylvicon 1990, held in Fredericton in February, the author presented a description of Stone Consolidated's approach to harvesting with respect to introducing the system of protecting advanced regeneration within our operations.

The application of CPRP in Quebec by industry has doubled between 1987 and 1988, from 52 400 ha to 113 800 ha (MER 1989) as indicated in Table 1. The 1988 figure represents 41% of total area cut in the Province.

In order to apply for credits for this treatment and to begin to better prescribe silvicultural treatments the company has begun to do precut inventory of natural regeneration in the field.

PREDICTION OF ADVANCED REGENERATION

Why is the prediction of advanced regeneration of importance to us as a company and what factors influenced our decision to spend time and money on attempting to reduce our ignorance?

I believe it is important to distinguish at what level we are attempting to make predictions.

At the stand level, to determine if advanced regeneration exists in quantity and is well distributed, one can visit the stand in its precut condition. The complexity of the problem begins to unfold when we try to predict the effect caused by our intervention, along with the ensuing competition factored in for good measure. The uncertainty that we wish to reduce is, certainly, the establishment period

of the future stand to a free-to-grow status, the yield expectation, and future stand composition.

At the forest level, the combination of possible yield, future developmental patterns, and silvicultural levels required, all impact on sustainable wood supply for the company and, hence, our future viability. The prediction of advanced regeneration impacts on the precut/postcut matrix of a wood supply analysis and has a direct bearing on short- and long-term silvicultural levels to be funded.

The calculation of sustainable wood supply was carried out by MER. One of the underlying stand development assumptions in this exercise was that, by applying methods which encourage protection of advanced regeneration, a reduction of 5 to 10 years in the time delay to free-to-grow status could be achieved on certain forest classes.

Certain obligations to maintain forest cover on public lands are defined in the CAAF in terms of total area to be treated by protection cutting. These acreages are not fixed, in the sense that an equivalent amount of work is acceptable if one can determine what these equivalent treatments are. Under forest management agreements (CAAF) in Quebec, companies may reduce stumpage payments as a result of applying protection cutting methods and respecting MER stocking norms. In order to qualify for this credit, a knowledge of the advanced regeneration present is required. Current rates are $20/ha, 50% lower than in 1989. These stumpage credits were an incentive to apply protection methods and offset additional operating costs. We have not determined the exact cost of applying the system, but no bonus is paid in the Saguenay Division on company operations. The method is applied on all operations in order to maintain worker consistency.

Predicting advanced regeneration allows us to formulate intensive silviculture prescriptions in advance. In harvest planning, we are able to designate sectors for winter cut in order to better protect existing regeneration. This is an important aspect to consider in order to reduce the need for replanting marginally stocked areas long distances from the mill.

We are able to maintain a stocking that is at least equivalent to the stand which existed beforehand. The opportunity remains for fill planting to bring additional areas up to or above norms. Given the budgetary constraints forest managers must deal with, we must invest our silvicultural dollars in the areas of greatest return.

PRESCRIPTION INVENTORY

One of our tools for determining advanced regeneration is a precut inventory. An inventory is carried out on all stands that are scheduled for harvest within 2 years. For each sample plot, four categories of information are collected.

1. Administrative details
   - map number,etc
   - stand classification,ecological region,etc

2. Biophysical information
   - age class
   - site index
   - trafficability
   - sylvicultural prescription
   - drainage
   - surface deposit

3. Dendrometric data
   - species/diameter
   - diameter/height(dominant or codominant)
   - age

4. Regeneration information

At each 1/40 ha sample plot, four circular subplots are established for regeneration assessment. A similar survey is also carried out on areas to be cut in 3 to 5 years time with the

same information collected but at a reduced intensity and at the forest unit level.

The objectives of the prescription inventory and management inventories are to:

1. Provide volume estimates of timber.
2. Reduce yield curve uncertainty at the forest unit level.
3. Improve precut/postcut estimates of stocking and species developments.
4. Prescribe silvicultural treatments.
5. Prescribe protection cutting method.
6. Select appropriate harvest season.
7. Collect site factors that affect productivity response.
8. Ensure appropriate link of stand condition to forest classes scheduled for harvest has been made.

The inventory is carried out during summer and fall months and all data are collected on hand-held data collectors. Data are downloaded at the camp level and compiled on PCs. Summarized tabular data are then transferred to the Division's geographic information system (GIS) to provide a complete updated information bank. this provides the necessary flexibility to carry out detailed analysis.

The type of information collected to date concerning regeneration has been the following: for softwood,intolerant hardwood, and tolerant hardwood regeneration, the presence or absence of a species or species group is indicated within a circular plot. Diameter of the plot varies for each group of species. A diameter of 1.13 m is used for softwood, 1.69 m for intolerant hardwood and 1.97 m for tolerant hardwood. There is no density count performed. Regeneration height class is indicated with the following code:

Code	Height class
0	Absence
1	Less than 10 cm
2	10 to 100 cm
3	100 to 300 cm
4	Less than 9 cm dbh & 300 cm

Quality of regeneration is indicated in the following manner.

Nil: Not present or very sparse

Light: Softwood regeneration present in low numbers (approx. 2000 st/ha) and very poorly distributed (stocking 50%). Planting possible.

Moderate: Regeneration light (5000 st/ha) and poorly distributed. developing towards an open stand. Planting or fill planting possible. (Stocking between 50 & 70%.)

Good: Regeneration abundant (8 to 10 000 st/ha) and well distributed (stocking 75% or greater).

Excessive: Very abundant (approx. 15 000 st/ha) density limiting growth. Thinning required in future.

A comment field allows evaluators to describe quality in terms of layering, insect damage or whatever information may influence the prescription.

This year we are considering applying ocular estimation, because the precision of estimating stocking in our particular forest conditions is not judged essential to maintain forest cover. In selected mixedwood stands or pine sites more detailed regeneration information can be collected. Our need to link appropriate

yield curve estimates with actual postcut stand development will be considered in follow-up postcut regeneration inventories.

SUMMARY

Evaluating advanced regeneration in the precut stage will continue to remain a priority for our company. With better understanding of cutover response, there is still a need to decrease the uncertainty surrounding yield estimates and to anticipate regeneration problems. A major part of our future lies in today's natural regeneration. Use it or lose it.

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NATURAL REGENERATION FROM SPROUTS AND ADVANCED GROWTH

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The general emphasis of this conference on the role of advanced regeneration in stand renewal is long overdue. Conducting silviculture without recognition of the importance of regeneration sources stored on site before final removal of cuttings is akin to running an auto engine on less than all its cylinders.

Historically, silviculture seems to have been based on the general notion that the only proper regeneration of forests comes from seedlings that germinate or are planted after some lethal disturbance has cleared a site of nearly all pre-existing woody vegetation. Any propagules that were there before have often been regarded as undesirable, malformed, or hopelessly stunted forms of growth. It is possible that this general idea emerged from the fact that much of the deliberate establishment of new forests has been on lands from which trees had been extirpated earlier. It also has a very valid and important ecological basis in the natural reestablishment of tree species after fires, landslides, or similar disturbances that leave sites essentially free of woody vegetation.

However, nature has other tricks up its sleeve and ones that we can take advantage of. The natural disturbances to which our evolutionarily primitive tree species respond include such things as wind and pests that tend to kill old forests from the top down. The species that respond to such disturbances tend to be the ones in which living propagules of varying kinds and degrees of dormancy are stored on the site. This category of species is even important after some kinds of fires, as in the case of sprout regeneration.

One could refer to the imitation of these different naturally regenerative disturbances by the names of the silvicultural regeneration methods, such as coppice, shelterwood, selection, and that kind of terminology about treatment or patterns of treatment. However, that way of looking at the situation diverts attention from the real source of the new stands.

The key to devising ways of regenerating forests should start from recognition and understanding the nature and life mechanisms of the small plants that are the regeneration sources. They develop one-by-one in units of area measured in fractions of square meters. The procedures that we call methods of regeneration actually involve looking at forest stands that come in units measured in hectares. Our first step should be to decide, on a small scale of area, on the source or sources of regeneration. Deciding how to arrange these small-spot sources in space and time is the second step in the design. The terminology of cutting methods is more about the second step than the first.

Stored forms of regeneration are sometimes more desirable than regeneration arising from post-disturbance dissemination. Regardless of whether or not they are acceptable, they have the very important virtue of being quite certain and dependable.

Tree species have many ways of perpetuating themselves by storing latent propagules on sites in ways such that they are ready to initiate rapid growth when released by regenerative disturbance.

ADVANCED REGENERATION

If there is any piece of silvicultural knowledge about which foresters in eastern North America have or should have learned and given to the world, it is the importance of advanced growth. The reason that this part of the world has so much of it is that a usually moist climate produces many forest habitats in which soil moisture is not severely limiting and fire is not the ruling lethal regenerative disturbance. These circumstances favor species that can become established and persist as stored advanced growth at low light intensity beneath old stands.

It is becoming increasingly apparent that many of the most important species of moist forests are dependent on starting as advanced growth under some sort of partial shade. This is true of almost all of the commercial eastern hardwood species. The chief exceptions are the birches and tulip-poplar, and even they tend to be favored by light shade. The most important eastern species that do not require shade in the early stages of life are the fire-following hard pines, such as jack pine, red pine, and the various southern pines. White pine, the spruces, balsam fir, hemlock, and northern white cedar are generally dependent on starting in partial shade.

Advanced regeneration is usually thought of as seedlings and saplings existing in arrested stages of development but retaining the capacity to respond to release with rapid growth. Sometimes, the term is also applied to trees of pole size and larger that are from the lower levels of stratified mixtures of species or of what are really the younger age classes of uneven-aged stands. The common denominator is the ability to renew comparatively rapid growth in height and crown expansion. In another paper at this symposium, Davis discusses the different forms of released advance growth of red spruce and the dominating role that they play in some stands that arose in eastern Maine about 1920.

Most species that regenerate as advanced growth do not grow rapidly in height during the early stages. From an evolutionary standpoint, they have not had to do so to survive. Instead, they have developed the adaptations that we call shade tolerance. Many of them also seem to curtail height growth while they develop the extensive root systems that can support rapid height growth after release. Because of their comparatively slow initial height growth, they do not lend themselves well to regeneration by planting. They often fall behind aggressive pioneer vegetation. However, if they can develop in partial shade, free of the close competition of pioneer vegetation, they can arrive at the stage where they can develop rapidly after release. The ideal forms are those which retain 100% live crown ration, pointed tops, and straight stems. Straightness of stem is associated with species, such as most conifers, sugar maple, and white ash, that are more nearly negatively geotropic than positively phototropic.

There are kinds of advance regeneration in the general category of seedling sprouts that can combine the advantages of both seedlings and sprouts. These start as normal seedlings but have tops that are killed back one or more times in ways that cause large root systems to develop. When such growth forms are released, they often shoot up fast and straight. The lignotubers of some eucalypts are special forms in which axillary buds enlarge and become woody storage organs as well as dormant buds.

The stunted grass stages of some pines are growth forms in which seedlings, usually of dry sites, do not initiate rapid height growth until large roots have developed.

There is even a planted kind of advanced growth, the planted seedling sprout. The best-known kind is the teak stump plant which is used throughout the tropics. These are tall year-old seedlings that are severely cut back at top and bottom. The tops are little more than

sprouting growing points but the remaining roots are fat and full of stored material. When planted, they shoot up fast. Matthew Kelty and others at the University of Massachusetts find that large-rooted seedling-sprouts of red oak planted in the same manner shoot up much faster than young seedlings that lack large root reserves.

SPROUT REGENERATION

Vegetative sprouts constitute a natural response to the killing of trees, large or small, by fire, browsing animals, or similar sources of damage. The coppice cutting methods that imitate these kinds of killing are perhaps the most ancient kind of regenerative silviculture. The tendency to hold sprout regeneration in low esteem is mostly the result of the crooked stem forms associated with coppicing on very short rotations over very many decades. With this kind of treatment, the sprout sources gradually change to large callousy bark-covered burls which develop very closely spaced dormant buds. The sprouts that arise from these burls are characteristically densely crowded; they compete so fiercely with each other that they often become stunted and crooked. These "burl-sprouts" are not common on this continent except where very frequent fires have had the same effect as very frequent coppice cutting.

When European ideas about silviculture were imported to our region, it was easy to infer that the coppice forests then common on the fuel-hungry North Atlantic seaboard were as undesirable as those of the Old World. It is now apparent that we missed the point that our coppice cuttings were far less frequent and that we were dealing with stump sprouts, which are actually rather uncommon and not well known in Europe.

Stump sprouts arise from dormant buds and develop in circles around parent stumps. While there are cases in which they become curved from one-sided crowding, they often develop into straight, well-formed stems. This has often resulted from natual thinning but it is clear that judicious artificial thinning would help. The rapid early height growth caused by large root reserves often actually improves the form of the trees. Many of the fine, large red oak veneer logs that now find their way to overseas markets are of stump-sprout origin. A large proportion of coast redwoods, the tallest trees on earth, have come from the "fairy-ring" circles of straight stump sprouts around huge stumps.

Root suckers developing from adventitious buds on the roots of some species can provide quite uniformly distributed sprouts. Trembling aspen, the most widespread tree species of North America, is so commonly of root-sucker origin that true seedlings are curiosities. While those are often good, we are less enchanted with root suckers of American beech, perhaps because they become too crowded to grow well. On the other hand, root suckers of sweet-gum are common and desirable.

What have been termed stool shoots of American beech are peculiar short-lived sprouts from adventitious buds developing from the vascular cambium of cut stumps. There is also the phenomenon of natural layering in which new trees can sprout up from ends of branches which, severed or still attached to the parents, are buried and form new roots. The northern white cedar and black spruce of sphagnum-bog forests are the most outstanding American examples of this kind of vegetative regeneration.

Viewpoints about sprout regeneration depend mostly on whether the species involved are regarded as valuable or as weeds. There is no form of regeneration that is more certain and it often produces trees of better stem form than was once supposed.

ROLE OF STORED REGENERATION IN SILVICULTURE

The utility of securing regeneration from any kind of pre-established plant depends mostly on the desirability of the species and of the growth forms that result. Advanced growth or sprouts of a given species can be highly desirable on one kind of site and weeds on another.

Stored forms of regeneration are the most dependable ones known to silviculture. One need not cast loose from the seed source represented by the old stand until the new one is in view. The opportunity to store new trees in quasi-dormancy usually provides much latitude about the timing of the cuttings. One need not wait for just the right time associated with a good seed year to start the new crop.

Sometimes site preparation with mechanical equipment, herbicides, or fire is necessary to reduce unwanted understory vegetation, to make vacant growing space for new seedlings, or to improve seedbed conditions. If it is, however, there is usually no need to wipe the slate clean of pre-existing vegetation. That will often encourage invasion by competing forms of pioneer vegetation that may have to be killed later; it is well to forestall situations in which one must spend money twice to kill competing vegetation.

With reliance on sprouts or advanced growth, one maintains some semblance of full occupancy of the growing space at all times. The new crop has already made part of its development beneath the old one and, therefore, has a head start on the next rotation. In this locality, if one manages to retain advance growth of spruce and fir during final removal cuttings, one may have a head start of 10 or 20 years on the next rotation. However, if the advance growth is destroyed or submerged in raspberries, the rotation may be set back by 10 or 20 years. This can add up to several decades of difference in useful production. Cutting a quarter off a rotation can pay for some more costly logging if that is the price to be paid.

There can be problems and drawbacks. One which is little more than a curiosity here is dwarf-mistletoe, which can spread from old trees to their progeny. Another is the tendency for any successful kind of natural regeneration to lead to excessive stand density. The best solution to that is the development of improved chemical and mechanical methods of pre-commercial strip thinning.

The main problem is protecting advanced growth from logging damage. However, one of the virtues of sprout regeneration is that it can sprout up again after logging damage. In fact, it may even grow up straighter for having been killed back to the ground. With advanced growth there is no substitute for developing logging equipment that fits the purpose and using it properly. We must view the process by which old stands are harvested and new ones established as a single integrated one. It would be very accidental if the cheapest kind of logging provided to optimum in that kind of integration.

While the forests of this region are very well adapted to use of these modes of stored regeneration, it is likely that their most important role will be in moist tropical forests. These constitute by far the most important item on the agenda of unfinished silvicultural business. It is becoming increasingly apparent that most of the better species are, like those of the eastern deciduous forest, dependent on starting as advanced growth beneath old stands. The species that germinate in truly sunlit gaps are mostly short-lived pioneers that function best as nurse-crops for the better species. Experiments with heavy cutting also reveal that sprout regeneration is just as important as it is in North American hardwood forests.

EFFECTS OF FOREST FLOOR DISTURBANCE ON SOIL SEED BANKS, GERMINATION AND EARLY SURVIVAL AFTER CLEARCUTTING A NORTHERN HARDWOOD STAND IN CENTRAL NEW BRUNSWICK

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ABSTRACT

The objectives of this study were to determine the effects of forest floor removal on seed availability, seed germination, and early survival of seedlings of woody species after clearcutting a northern hardwood forest in central New Brunswick. After harvesting in the winter of 1988, 30 pairs of 1-m^2 plots were established in the clearcut in May 1988. The forest floor was removed from one plot of each pair to simulate forest floor disturbance caused by skidding or site preparation. The second plot of each pair was left as a control. Soil cores were taken from each disturbed and undisturbed plot in May 1988 to assess the abundance and composition of the seedbanks. Seedfall was collected from May 1988 to November 1989, in one seed trap placed adjacent to each plot. Residual seed banks (seeds 1-year-old) were assessed by collecting additional soil cores from underneath the seed traps in May 1989, to determine if seeds of the major woody species remain viable in the forest floor for 1 year or more. Germination tests were conducted on all soil cores in germination chambers. Field germination and survival of all seedlings was followed in all plots from May, 1988, to November 1989. Survival and growth of advance regeneration in the undisturbed plots was followed and the percent cover of ground vegetation was estimated in 1989. Temperature and moisture conditions in the surface 1-cm layer of the soil (disturbed plots) or litter (undisturbed plots) were monitored during the 1989 growing season in five plot pairs. There were 9.5 million and 1.4 million germinable seeds of woody species in the seed banks from the undisturbed and disturbed plots, respectively. Most seeds were in the litter layer and consisted mostly of yellow birch and raspberry. Yellow birch and raspberry seeds remained germinable after 1 year of storage in the seed banks, although the numbers were greatly reduced. In spite of reduced seed availability on the disturbed plots, germination and survival of yellow birch was higher on the disturbed plots in both years. This was also true of raspberry in 1988 but, in 1989, germination was higher on the undisturbed plots, probably because of the greater number of seeds in the forest floor. Survival was about the same on the two treatments for raspberry in 1989. The average maximum temperatures were higher and the average minimum temperatures were lower on the undisturbed plots as compared to the disturbed plots. High lethal temperatures also occurred more frequently on the undisturbed plots. Moisture content was generally higher in the undisturbed plots but was more frequently below the wilting point. The higher mortality of new germinants in the undisturbed plots was apparently related to the occurrence of high lethal temperatures and increased moisture stress. The total percent cover of ground vegetation was nearly the same in the two treatments. Cover differed by height class, however, indicating that competitive relationships were different on the treatments. At the end of the second growing season, vegetative stems and new germinants of raspberry along with new germinants of yellow birch predominated on the disturbed

plots. On the undisturbed plots, vegetative stems of raspberry were most abundant, followed by sugar maple advance regeneration and new germinants and advance regeneration of striped maple. There were nearly twice as many total stems on the disturbed plots as compared to the undisturbed plots. Silvicultural treatments should be designed to avoid displacing seed sources of desired species from large areas and to create favorable seedbeds for germination and survival. Further research into the relationships between environmental factors and germination and survival of seedlings is needed.

Key words: Forest floor disturbance; germination; natural regeneration; northern hardwoods; seed banks; seed fall; soil moisture; soil temperature; survival.

INTRODUCTION

The goal of regeneration research is to improve our understanding of the factors and processes that control natural regeneration so that, ultimately, we can predict the species composition, stocking, and density of natural regeneration at the stand level with reasonable accuracy before harvesting. Natural regeneration is notoriously variable, however, because it is controlled by a large number of interacting biological, climatic, and edaphic variables (Greaves *et al.* 1978). Even within an individual stand where macro-scale factors, such as climate, soil conditions, preharvest stand composition, and the harvesting system are relatively uniform, regeneration may still be highly variable. This residual variability is related to micro-scale factors, including forest floor disturbance patterns, availability of seed sources, animal browsing, and microclimate, among others.

In this study, we focus on forest floor disturbance and seed availability because these two factors can be controlled to a large extent by the way the stand is harvested. With this information, silvicultural treatments can be designed to produce the desired results. The degree of forest floor disturbance affects the receptivity of the seedbed and the environmental factors (temperature, light, moisture, etc.) that control germination of seeds and survival of seedlings. Harvesting disturbance also affects the amount of advance regeneration in the cutover and the ability of stumps and root stocks to sprout or sucker. The available seed sources may be in the form of stored seeds in the forest floor from previous years or seeds dispersed in the years during and after the harvest from the stand margin or residual trees.

Previous experience indicates that regeneration from new germinants after harvesting can be significant but highly variable in northern hardwood stands. In the Nashwaak Experimental Watershed, New Brunswick, new germinants and advance regeneration each accounted for about 44% of the stems one year after harvest. The remaining 12% of stems was made up of sprouts and suckers (Roberts *et al.* 1989). Six years after clearcutting of a 60-year-old northern hardwood forest in New Hampshire, 60% of the largest individuals were of new germinant origin (Bormann and Likens 1979). These patterns differ from spruce-fir stands in which 85% of the stems may be advance regeneration (Godin 1986).

The percentage of stems from each origin would be expected to differ by species. In the Nashwaak study (Roberts *et al.* 1989), most stems of yellow birch, red maple, white birch, trembling aspen, and white ash were new germinants. Sugar maple and striped maple originated mostly from advance regeneration, whereas beech, red-berried elder, and willow were mostly sprouts or suckers. The percentage of total stems that were yellow birch varied from 0 to 47% in the 16 sample plots. It was hypothesized that much of this variability might result from differences in seed availability and forest floor disturbance.

Table 1. Species composition before clearcutting based on tallies of stumps ≥ 2.0 cm diameter in fifteen 100 m^2 plots.

Species	Density # Stems	Density %	Basal Area m^2	Basal Area %	Frequency[a] %
Sugar maple	146	49.2	4.2799	47.3	100
Beech	81	27.3	1.7969	19.9	93
Yellow birch	16	5.4	0.5631	6.2	53
Red maple	28	9.4	1.9783	21.9	67
Striped maple	23	7.7	0.4033	4.5	67
Spruce	3	1.0	0.0279	0.2	20
Total/1500 m^2	297	100.0	9.0494	100.0	
Total/ha	1980		60.3293		

[a] Frequency is calculated as the percentage of plots in which the species occurred.

The current study was designed to clarify the process of regeneration from seed after clearcutting a northern hardwood forest. Specifically, the objectives were to: 1) quantify seed availability under two levels of forest floor disturbance (organic layer removed, organic layer undisturbed), and 2) determine the effects of forest floor disturbance on seed germination and early survival of woody species.

METHODS

Study Area

A 1.25 ha clearcut portion of a northern hardwood stand in central New Brunswick (46°10'N latitude, 66°51'W longitude), 30 km northwest of Fredericton, was selected for study. The area is in the sugar maple - yellow birch - fir zone (Loucks 1962). Before harvesting, the stand was dominated by sugar maple, beech, red maple, and striped maple, in decreasing order of abundance (Table 1). The soil is a stony silt loam to sandy clay loam, underlaid by bedrock of Pennsylvanian sandstone. The clearcut is rectangular in shape (250 m x 50 m), with the long axis oriented in a north-south direction. The study area is on a ridge top with a 5-10% slope and north to west aspect. Adjacent to the clearcut on the east side is an untreated 2-year-old clearcut; the mature hardwood forest borders the other three sides. The mean annual temperature is approximately 3.1°C and the frost-free period is 161 days. The mean annual rainfall and snowfall are 724 mm and 298 mm, respectively (van Groenewoud 1983). The stand was harvested in January - February, 1988, using chainsaws and skidders.

Field Methods

The clearcut was stratified into 10 sections of equal area and three points were randomly located within each section. At each point, two 1-m^2 plots were established in the closest location that was free of exposed rocks, heavy slash, or stumps. A total of 30 plot pairs (60 plots) were established.

In one plot of each pair, the organic layer was completely removed by hand, using a rake and mattock. The organic layer was also removed from a 0.5 m wide buffer strip surrounding the plot. The second plot of each pair was left undisturbed as a control. Plot establishment and disturbance treatments were completed in May 1988, before seed dispersal of any of the major tree and shrub species occurred. The purpose of the disturbance treatment was to

simulate the exposure of mineral soil caused by skidding or site preparation. The control provided undisturbed forest floor conditions which would likely be common in an untreated clearcut.

To assess seed banks, four 10.2 cm diameter soil core samples were extracted from the buffer strips of each plot in May 1988. The samples from the control plots were separated into the organic layer and the top 10 cm of mineral soil. Only the top 10 cm of mineral soil was collected from the disturbed plots. Each sample was placed in a plastic bag and stored at 1-4°C until laboratory germination tests were conducted. Because of the limited capacity of the laboratory germinators, half of the samples from each treatment were stored for one month while the germination test was conducted on the remaining samples. The test was carried out in germination chambers for 28 days with standard conditions prescribed by Edwards (1987) for hardwood tree species (15 hrs light at 30°C, 9 hrs dark at 20°C). New germinants were tallied by species at weekly intervals. At the end of the 28-day period, unidentified germinants were transplanted and placed in a greenhouse but many of these died before they could be identified.

A 26 cm x 52.5 cm seed trap was placed on the ground adjacent to each plot in June 1988, to determine seed inputs to the plots. Seeds were collected about once a month from October to December 1988, and twice more in May and October, 1989. A cutting test for seed viability was performed on the collected seeds; only full seeds with apparently fresh embryos were considered viable.

Soil core samples were taken again in May 1989, to determine if seeds in the seed banks remain viable for more than one year. These samples were taken from underneath the seed traps so that the seeds collected were at least 1 year old. Germination tests were carried out as in 1988.

Field germination and survival of seedlings was followed in all plots throughout the 1988 and 1989 growing seasons. Each new germinant was identified and marked when it first emerged, and then checked for survival at weekly intervals. Notes on the condition of each germinant were taken to trace the fate of each seedling and determine possible causes of mortality. The height of each surviving germinant was measured at the end of the 1988 growing season, and at the beginning and end of the 1989 growing season to evaluate the growth and competitive status of each seedling.

To assess the effects of forest floor disturbance on the seedling environment, soil temperature and moisture in the 1-cm surface layer were monitored in five plot pairs during the second growing season (June - October 1989). Two copper-constantan thermocouples were placed in the buffer strips adjacent to each plot and hourly average temperatures based on three readings at 20 minute intervals were recorded using a micrologger. Moisture content of the surface 1-cm layer was determined gravimetrically at weekly intervals. Two samples from the buffer strip of each plot were returned to the laboratory, weighed, oven-dried at 105°C to constant weight, and reweighed. The differences in temperature and moisture between the treatments were examined for possible relationships with germination and survival patterns.

The percent cover and heights of advance regeneration and ground vegetation were evaluated to assess the possible competitive effects on seedlings. Each stem of advance regeneration in the undisturbed plots was marked in June 1988. Survival of each individual was monitored throughout the 1988 and 1989 growing seasons. The height of each stem was measured at the beginning and end of each growing season. The percent cover of ground vegetation (including advance regeneration) was estimated in three height

Table 2 Number of germinable seeds in the seed banks by treatment, layer and species immediately after clearcutting (May 1988).

Species	Undisturbed plots			Disturbed plots		
	Mean No.[a] Seeds/m^2	SE[b]	Total No. Seeds/ha	Mean No. Seeds/m^2	SE	Total No. Seeds/ha
Litter layer						
Yellow birch	349.86	35.54	3,498,600	–		–
Raspberry	164.22	25.22	1,642,200	–		–
Striped maple	3.06	2.25	30,600	–		–
Others	239.70	50.27	2,397,000	–		–
Subtotal	756.84	76.73	7,568,400	–		–
Mineral soil layer						
Yellow birch	126.48	17.09	1,264,800	59.16	8.92	591,600
Raspberry	34.68	17.41	346,800	31.62	6.64	316,200
Striped maple	–	–	1.02	1.02	10,200	
Others	37.74	9.24	377,400	49.98	11.22	499,800
Subtotal	198.90	25.70	1,989,000	141.78	17.39	1,417,800
Grand total	955.74	95.87	9,557,400	141.78	17.39	1,417,800

[a] N = 120 soil cores (30 plots x 4 cores/plot). The inside diameter of the core was 10.2 cm (81.71 cm^2).

[b] Standard error of the mean.

layers, 0-10 cm, 10-30 cm, and 30 cm, as well as for all layers combined. Each estimate was the average of two observations made independently by two estimators. The estimation was conducted in June and August 1989.

RESULTS AND DISCUSSION

Seed Banks and Seedfall

A large seed bank of woody species was found immediately after clearcutting (Table 2). The total number of germinable seeds in the undisturbed plots was 9.5 million/ha. In contrast, there were 1.4 million seeds/ha in the disturbed plots, of which the majority should have been from seed deposits in previous years because most of the seeds dispersed from fall 1987 to spring 1988 were probably removed with the treatment (Moore and Wein 1977). The majority of the seeds occurred in the litter layer; only 20%, approximately, of the seeds were found in the mineral soil. Each species showed the same pattern, with up to eight times as many germinable seeds in the undisturbed plots as in the disturbed plots. Yellow birch and raspberry were the most abundant species, although unidentified species made up approximately 30% and 35% of the total number of seeds in the undisturbed and disturbed plots, respectively. Only three seeds of striped maple germinated in the samples from the undisturbed plots and one seed from the disturbed plots.

A large number of seeds maintained their germinability in the undisturbed and disturbed plots after 1 year of storage in the forest floor, although the numbers were greatly reduced (Table 3). The differences between 1988 and 1989 were significant (Student's t-test, $p < 0.05$) by layer for all species combined and for each species separately except for raspberry. These results indicate that regeneration of yel-

Table 3 Number of germinable seeds in the residual seed banks by treatment, layer, and species 1 year after clearcutting (May 1989).

Species	Undisturbed plots			Disturbed plots		
	Mean No.[a] Seeds/m^2	SE[b]	Total No. Seeds/ha	Mean No. Seeds/m^2	SE	Total No. Seeds/ha
Litter layer						
Yellow birch	142.70	26.79	1,427,000	–		–
Raspberry	40.70	9.42	407,000	–		–
Others	40.77	11.12	407,700	–		–
Subtotal	224.17	31.38	2,241,700			
Mineral soil layer						
Yellow birch	6.42	6.42	64,200	12.20	6.80	122,000
Raspberry	6.42	6.42	64,200	4.07	4.07	40,700
Others	–		–	0		–
Subtotal	12.84	8.82	128,400	16.27	7.70	162,700
Grand total	247.68	40.65	2,476,800	16.27	7.70	162,700

[a] N = 60 soil cores for litter layer (30 plots x 2 cores/plot) and N = 19 soil cores for mineral soil layer.

[b] Standard error of the mean.

[c] N = 30 soil cores for mineral soil layer (30 plots x 1 core/plot).

low birch and raspberry may be derived from seed dispersed 2 years before harvesting. Although the buried seed strategy has been demonstrated for species such as raspberry and pin cherry (Marks 1974; Bormann and Likens 1979), it is not clear whether seeds of the common hardwood tree species will remain viable in the forest floor for more than 1 year. Our study confirms the finding of Marquis (1975) that yellow birch seed can remain viable for at least a full year.

The seedfall was strongly dominated by yellow birch (Table 4). There were more species in the seedfall than in the seed banks, including sugar maple, mountain maple, red maple, white birch, spruce, balsam fir, and white ash.

Field Germination and Survival

In 1988, there were large differences between treatments in the germination and survival patterns of yellow birch (Figure 1) and raspberry (Figure 2). Cumulative germination and survival of yellow birch peaked in mid-July in both treatments. After mid-July, survival was lower in the undisturbed plots. Patterns for raspberry were similar to yellow birch in the undisturbed plots, but in the disturbed plots, cumulative germination and survival peaked a month earlier (Figure 2).

The germination and survival patterns in 1989 differed somewhat from those in 1988 for yellow birch (Figure 3). More germination occurred on the disturbed plots and less on the undisturbed plots, resulting in a greater difference between the treatments in 1989. Germination and survival again peaked in July on both treatments. The increased germination on the disturbed plots was probably largely the result of seed inputs from seedfall in 1988 along with surviving germinable seeds in the seed banks. In addition, the mineral seedbeds

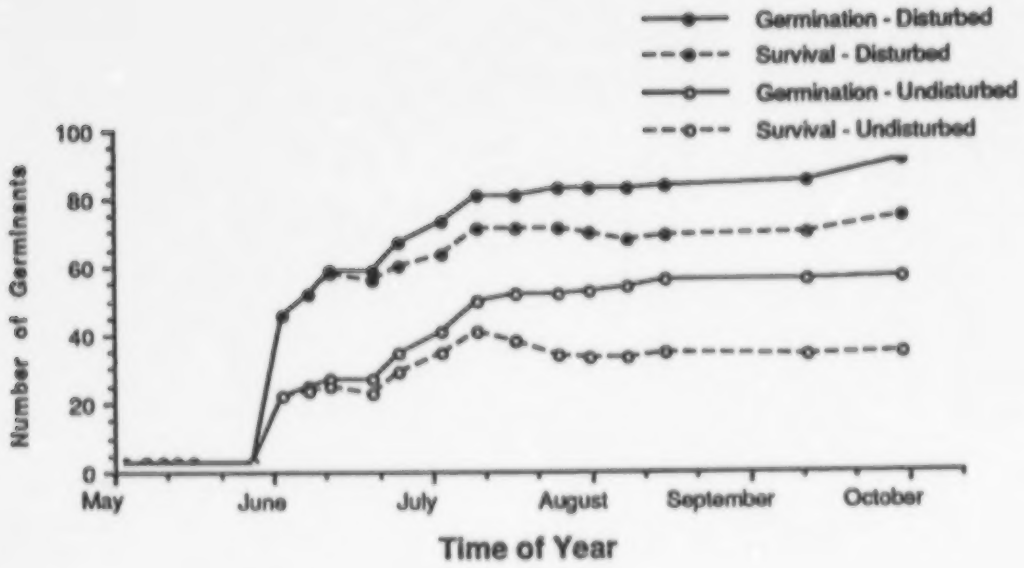

Figure 1 Cumulative germination and survival of yellow birch in 1988.

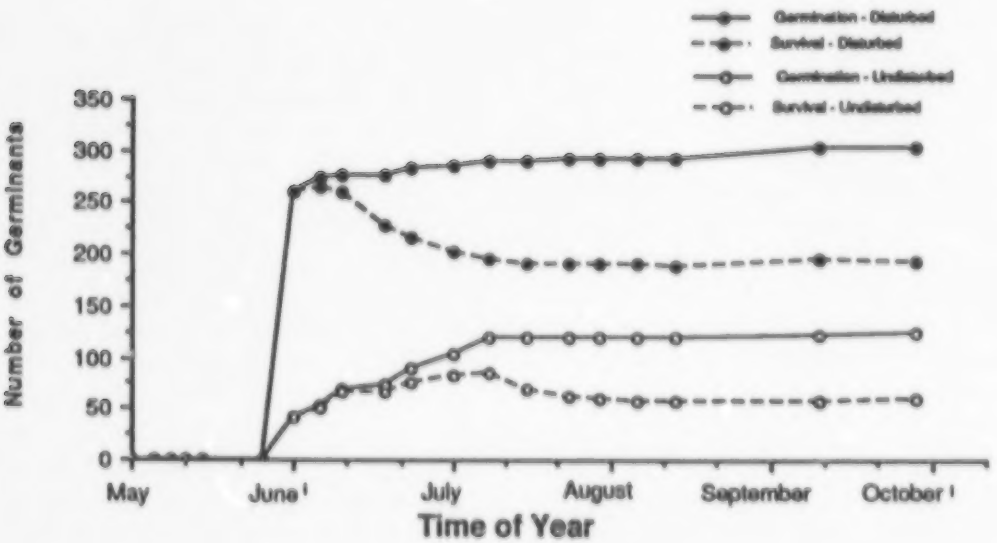

Figure 2 Cumulative germination and survival of raspberry in 1988.

Table 4 Seedfall by species from June 1988 to November 1989.

Species	Mean No. Seeds/m^2	SE	Mean No. Viable seeds[a]/m^2	SE
Sugar maple	20.51	2.70	7.20	1.33
Striped maple	9.52	1.60	7.57	1.29
Mountain maple	0.37	0.21	0.37	0.21
Red maple	0.60	0.50	0	–
Yellow birch	105.65	0.27	53.55	5.59
White birch	7.96	1.34	4.46	0.84
Spruce *spp.*	12.30	1.57	8.92	1.38
Balsam fir	3.50	0.83	3.26	0.80
Raspberry	1.21	0.81	0.96	0.61
White ash	0.12	0.12	0.12	0.12
Total	161.74	12.39	86.41	6.73

[a] Only seeds with fresh and fully developed embryos were considered viable as determined by a cutting test.

were still essentially bare and would still have been receptive for yellow birch germination.

For raspberry, cumulative germination in the undisturbed plots in 1989 peaked at about the same time and same level as in 1988, although germination began several weeks earlier in 1989 (Figure 4). Germination was much lower in 1989 than 1988 on the disturbed plots, resulting in lower germination than on the undisturbed plots. In addition, the survival of new raspberry germinants was much lower in 1989 than 1988 in both treatments. The lower germination in 1989 on the disturbed plots may have been the result of germination of most of the stored seeds in 1988 and the lack of replenishment in 1989 (Table 4). The number of seeds in the residual seed banks in 1989 on the undisturbed plots was over 11 times greater than the number on the disturbed plots (Table 3) which probably accounted for the higher germination on the undisturbed plots in 1989.

Temperature and Moisture Conditions

There were marked differences between the treatments in certain aspects of surface temperature. The average maximum temperatures in the undisturbed plots were generally higher than in the disturbed plots throughout most of the 1989 growing season (Figure 5). This was especially true during warmer periods which occurred in late May, mid-June, and July-August. The overall average daily maximum temperature for the entire measurement period was significantly higher on the undisturbed plots than on the disturbed plots (Student's t-test, $p < 0.05$). The average minimum temperature was lower in the undisturbed plots than the disturbed plots, especially during the period from late June to early September (Figure 6). Again, the difference was significant (Student's t-test, $p < 0.05$) when the means were calculated over the entire measurement period. Average mean temperatures were similar in the two treatments except at a few dates when temperatures were the highest, at which time the undisturbed plots were warmer than the disturbed plots (Figure 7). The overall seasonal average

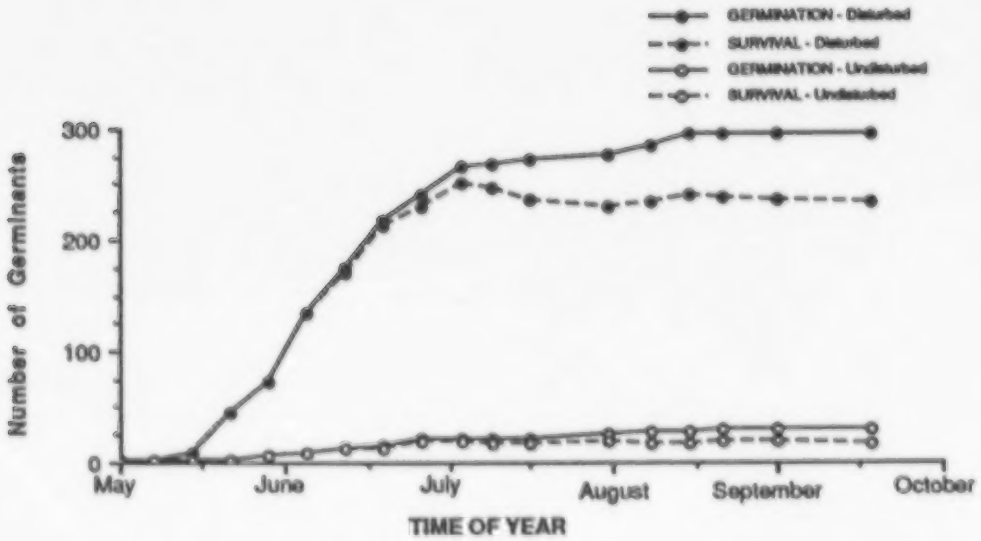

Figure 3 Cumulative germination and survival of yellow birch in 1989.

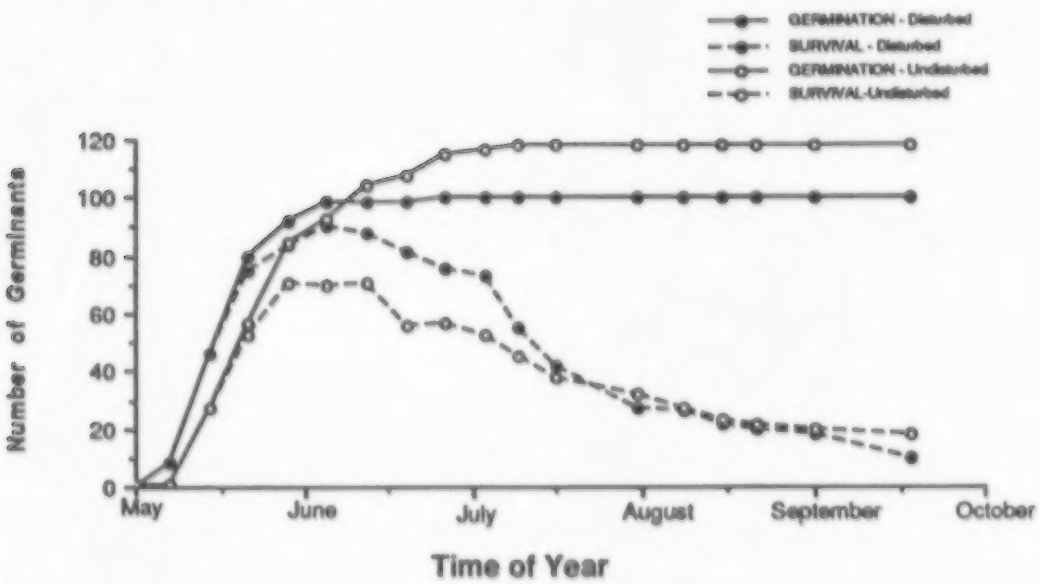

Figure 4 Cumulative germination and survival of raspberry in 1989.

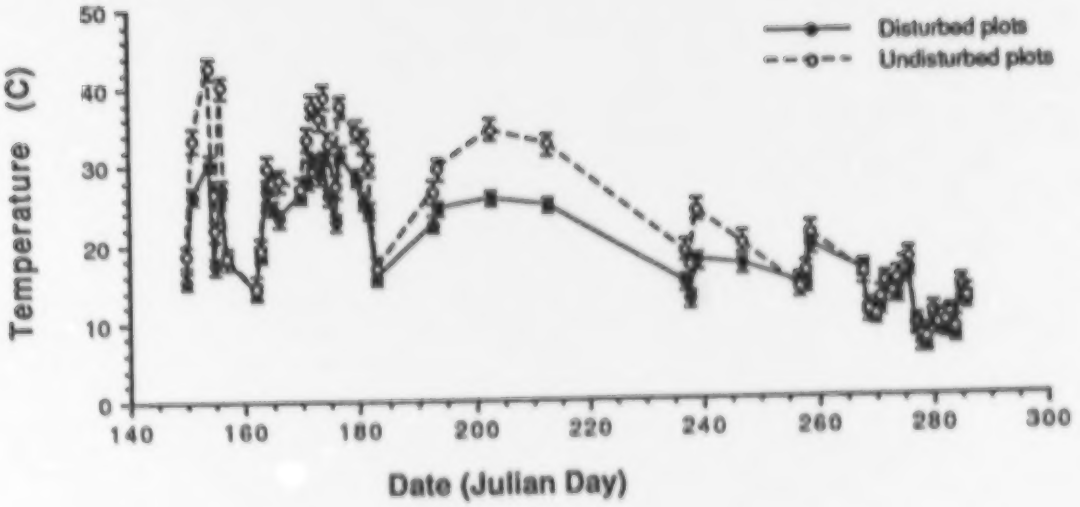

Figure 5 Average maximum temperatures in the undisturbed plots and disturbed plots in 1989. Bars indicate +/- one standard error of the mean (N=5).

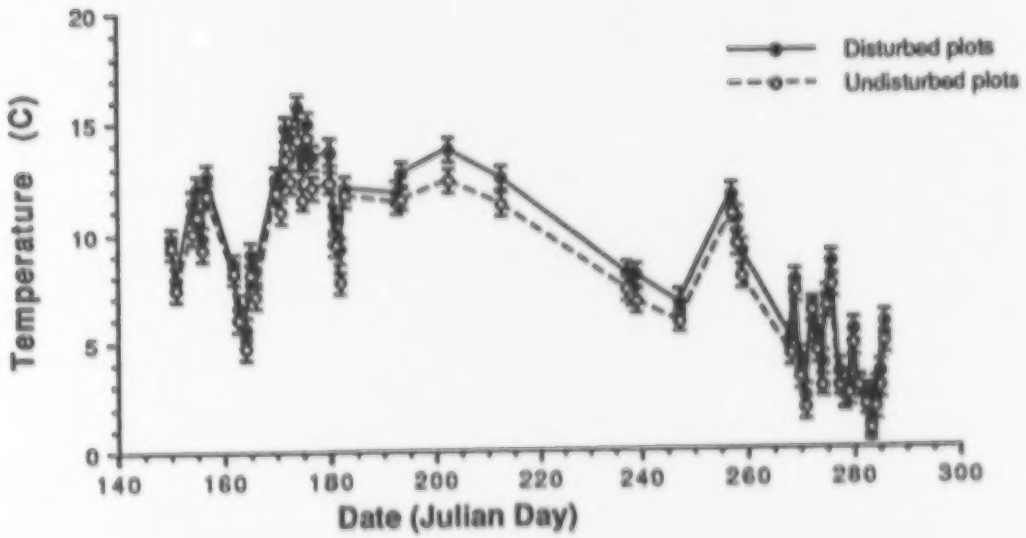

Figure 6 Average minimum temperatures in the undisturbed plots and disturbed plots in 1989.

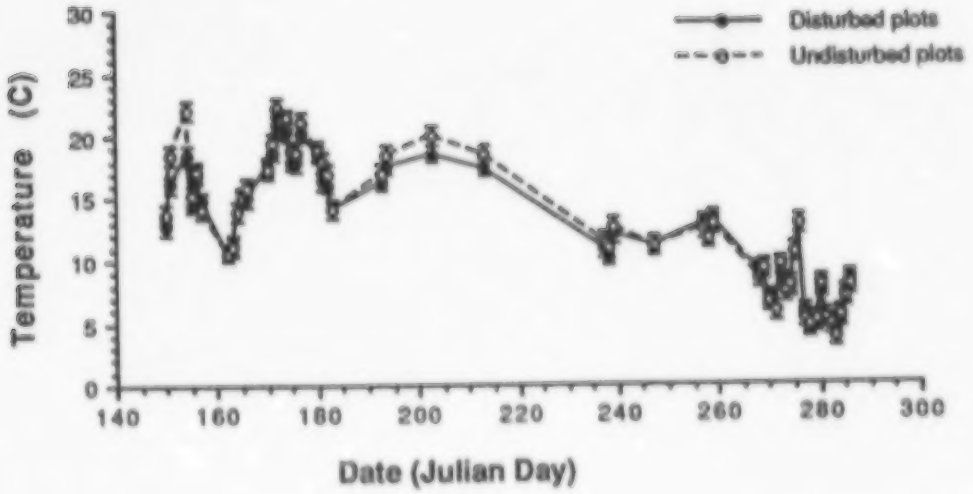

Figure 7 Average mean temperatures in the undisturbed plots and disturbed plots in 1989.

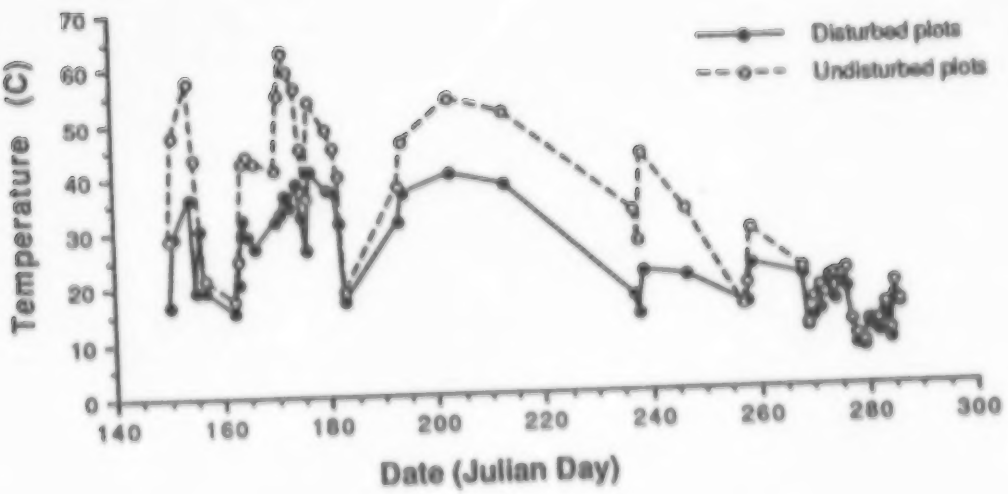

Figure 8 Extreme high temperatures in the undisturbed plots and disturbed plots in 1989.

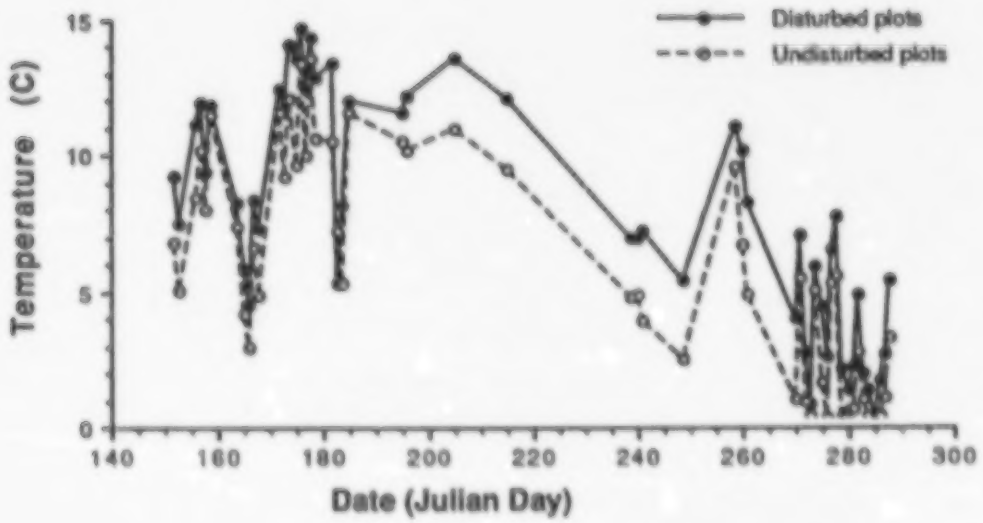

Figure 9 Extreme low temperatures in the undisturbed plots and disturbed plots in 1989.

mean temperatures were not significantly different between treatments. These results indicate that the surface layer in the disturbed plots tended to be cooler during the warmest portion of the 24-hour period and warmer during the coolest portion of the 24-hour period as compared to the undisturbed plots. Consequently, temperature conditions in the undisturbed plots were more variable.

Extreme high and low temperatures are probably of primary importance to seedling survival because they may cause heat or frost damage to seedlings. High lethal temperatures, defined as >42°C (Hungerford and Babbitt 1987), occurred frequently throughout the 1989 growing season on the undisturbed plots (Figure 8). High lethal temperatures rarely occurred in the disturbed plots. Although the extreme low temperatures were lower in the undisturbed plots than in the disturbed plots, no low lethal temperatures (≤ 0°C) were observed in either treatment (Figure 9).

The spot checks of moisture conditions revealed that the occurrence of moisture content above the wilting point was more frequent in the disturbed plots than in the undisturbed plots, even though the moisture content was generally higher in the undisturbed plots (Figure 10). The wilting points were determined by placing samples of the surface 1-cm layer (litter or mineral soil for the undisturbed and disturbed plots, respectively) in a pressure chamber at 1.5 MPa (15 bars) pressure for 48 hours (Richards and Fireman 1943). These differences indicate that moisture availability in the surface 1-cm layer is higher in the disturbed plots than in the undisturbed plots.

Mortality of raspberry, striped maple, and pin cherry new germinants corresponded closely to the occurrence of high lethal temperatures in the surface 1-cm layer in the undisturbed plots. Mortality began to occur in early June at the time when the high lethal temperatures began to occur. High lethal temperatures repeatedly occurred during the following 2-month period when most of the mortality also

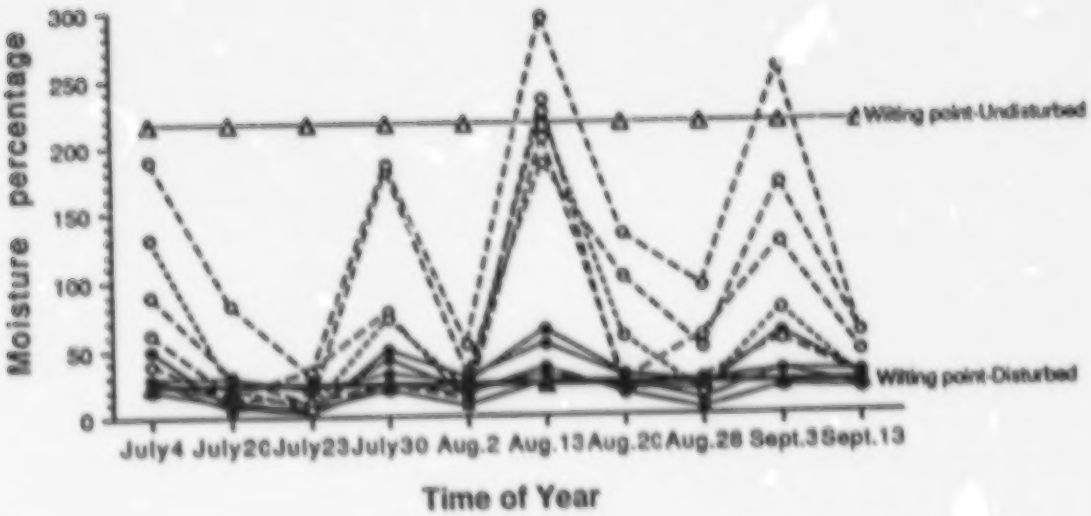

Figure 10 Percent moisture content (by weight) in the surface 1-cm layer in the undisturbed plots and disturbed plots in 1989.

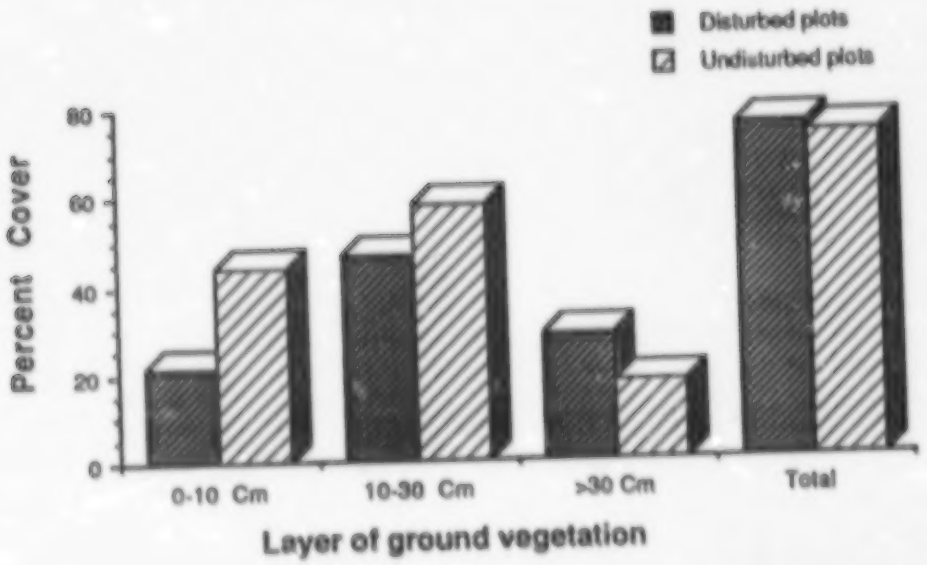

Figure 11 Percent ground cover on June 22, 1989, in three layers and all layers combined in the undisturbed plots and disturbed plots.

took place. There seemed to be little effect on the survival of yellow birch new germinants in the undisturbed plots. Hungerford and Babbitt (1987) found that the lethal temperature threshold (≥ 2 hours at 36°C or ≥ 1 hour at 42°C) occurred on 14-37% of the days during the growing season on a clearcut. They concluded that higher surface temperatures on the clearcut not only increased the potential for seedling mortality, but also caused drying of the surface layers which created additional moisture stress. The drier surface conditions in turn lowered the volumetric heat capacity and thermal conductivity which further increased temperature variation. Tubbs (1969) found that mineral soil surfaces were much cooler than organic surfaces in full sunlight. Temperatures as high as 51°C were recorded on the organic surface. Germination and survival of yellow birch were higher on the cooler and moister mineral seedbeds. Marquis (1969) also found high surface temperatures to be a direct cause of birch seedling mortality on humus seedbeds exposed to full sunlight. The results of the current study confirm these observations.

Ground Cover

The mean percent ground cover in June 1989, was greater in the undisturbed plots than the disturbed plots for the two lowest layers (0-10 cm, 10-30 cm) (Figure 11). There was more cover in the uppermost layer (> 30 cm), however, in the disturbed plots. Total cover was virtually the same on the two treatments. On the disturbed plots, the 1-year-old raspberry canes made up most of the vegetation cover, whereas a variety of species of generally lower stature constituted the vegetation cover on the undisturbed plots. In the disturbed plots, the percent survival of raspberry new germinants in 1989 was significantly correlated with percent vegetation cover in the 10-30 cm and 30 cm layers, as well as the total percent cover ($r = -0.55$ to -0.61, $p < 0.01$). This suggests that suppression was the major cause of raspberry mortality in the disturbed plots. The correlations were not significant for other species in the disturbed plots, nor were they significant for any species in the undisturbed plots. The effect of suppression on survival in the undisturbed plots may have been masked by the overriding effect of temperature.

Regeneration Composition

Total regeneration at the end of the second growing season after clearcutting, including advance regeneration and vegetative stems, as well as new germinants, is summarized in Table 5. Because tree stumps were deliberately avoided in establishing the plots, stump sprouts were not included in the regeneration.

The total number of stems in the disturbed plots was nearly twice the number in the undisturbed plots. New germinants and vegetative stems each accounted for roughly half of the regeneration in the disturbed plots. Vegetative stems also comprised nearly half (41%) of the regeneration on the undisturbed plots but new germinants made up a much lower proportion (26%) of the stems on this treatment. Advance regeneration was relatively important in the undisturbed plots.

In general, the regeneration in the undisturbed plots was composed predominantly of raspberry, sugar maple, and striped maple; yellow birch, hobblebush, and alternate-leaved dogwood were secondary in importance. The disturbed plots were more strongly dominated by raspberry and yellow birch, with trembling aspen and elderberry as secondary species. Thus, the overall effect of forest floor disturbance on regeneration was to eliminate advance regeneration of shade-tolerant species and promote the regeneration of intolerant and midtolerant species.

CONCLUSIONS

A large germinable seed bank of 9.5 million seeds/ha of woody species was found in the undisturbed forest floor after clearcutting.

Table 5 Summary of regeneration (stems/ha) at the end of the second growing season after clearcutting by species, treatment, and origin of regeneration.

Species	Disturbed plots		Undisturbed plots		
	New germinants	Sprouts or suckers	New germinants	Advance regeneration	Sprouts or suckers
Striped maple	–	–	23,330	14,670	–
Red maple	–	–	–	1,330	–
Beech	–	3,700	–	2,330	3,300
Dogwood	–	300	–	8,330	1,700
Hobblebush	–	–	–	11,670	–
Mountain maple	–	–	–	7,330	–
Sugar maple	300	–	2,000	36,000	–
Pin cherry	3,670	–	8,000	–	–
Spruce & fir	4,330	–	1,000	–	–
Yellow birch	99,670	–	12,670	–	–
Trembling aspen	29,300	–	–	–	–
Willow	1,330	–	–	–	–
Raspberry	63,330	214,300	18,000	–	93,000
Elderberry	–	14,700	–	–	2,300
Total	201,930	233,000	65,000	81,660	100,300
Treatment total	434,930	246,960			

Yellow birch and raspberry accounted for the majority of seeds that were positively identified, with yellow birch predominating. Forest floor removal dramatically reduced the number of seeds in the seed banks, especially large seeds of species such as striped maple. Seeds in the mineral soil layer were mainly of small seeded species such as yellow birch and raspberry. It must be noted, however, that the removed seeds were merely displaced and would probably result in higher recruitment in the areas where they were deposited. In harvesting operations, it is important to be aware of the potential effects of the treatments on the distribution of seeds and seedbed types which subsequently affect the distribution of regeneration.

Yellow birch remained the predominant species in the residual seed banks in both treatments after 1 year of storage in the forest floor, implying that stored seeds continued to be an important source of germination in the second growing season after clearcutting. Abundant seedfall in 1988-89, especially of yellow birch, probably also accounted for a large proportion of the new germinants in 1989. Because of the proximity of the mature stand to the clearcut, a variety of species were represented in the seedfall.

Forest floor removal and mineral soil exposure encouraged germination of small seeded species, including yellow birch, raspberry, trembling aspen, spruce, and fir. Large seeds were removed with the disturbance; therefore, germinants of large seeded species such as striped maple did not occur in the disturbed plots. Differences in germination patterns between years seemed to be at least partly related to the number of available seeds. Forest floor disturbance also improved survival of new germinants of most species.

Temperature variations in the surface 1 cm were reduced by the disturbance treatment.

The higher mortality of new germinants in the undisturbed plots was apparently related to the frequent occurrence of high lethal temperatures. Although the percent moisture content by weight was higher in the surface 1 cm on the undisturbed plots as compared to the disturbed plots, the moisture content was more frequently below the wilting point. This placed additional stress on the new germinants in the undisturbed plots.

The vertical structure of the vegetation differed in the two treatments, indicating that the competitive relationships were different in the two treatments. The percent cover in the tallest height class (> 30 cm) was greater on the disturbed plots, whereas cover in the shorter classes (< 30 cm) was greater in the undisturbed plots. The greater abundance and greater height of raspberry in the disturbed plots accounted for this difference and may have caused mortality of new germinants by suppression.

In terms of the number of stems of tree species, new germinants of yellow birch and trembling aspen dominated the regeneration in the disturbed plots. In the undisturbed plots, however, advance regeneration of sugar maple and striped maple, along with new germinants of yellow birch and striped maple, dominated the regeneration. New germinants and vegetative stems of raspberry were prolific in the disturbed plots and provided intense competition for the tree species. In contrast, there was less competition from raspberry in the undisturbed plots. In addition, the shade-tolerant species which occurred in greater abundance in the undisturbed plots are better able to survive shaded conditions.

Natural regeneration from seed is usually a highly variable but important part of the total regeneration picture. An understanding of the basic ecological processes that control seedling establishment is needed to predict the species composition, density, and stocking of regeneration. As illustrated in this paper, localized variations in seed availability have a strong effect on regeneration composition and density. Seed availability in turn is controlled by a number of key ecological processes which affect the production of seeds (seedfall) and the longevity of seeds in the soil seed banks. In addition, seed availability is affected by the disturbance which may redistribute seeds to varying degrees depending on the type of disturbance. Germination and survival of seedlings are affected by other factors and processes, including seedbed conditions, the seedling environment (especially temperature and moisture), and competition, which again may be affected by the nature and intensity of the disturbance. These factors and processes are not unique to hardwood stands; only the relative importance of specific factors might vary by stand type.

Further research into the interactions between the harvesting disturbance and basic ecological factors such as seed availability, the seedling microenvironment, and competitive relationships within the developing vegetation will help provide the information needed to manage natural regeneration. Previous research has demonstrated that mineral seedbeds are favorable for the establishment of seedlings and this information has been incorporated into silvicultural guides (Tubbs 1977, Leak *et al.* 1987). More work is needed, however, to identify the sources of seed for this regeneration and to clarify the relationships between environmental factors and the survival and development of the seedlings.

RECOMMENDATIONS

1. If natural regeneration of sugar maple is desired, intensive forest floor disturbance should be avoided to protect sugar maple advance regeneration.

2. If yellow birch is desired, forest floor disturbance and mineral soil exposure should be created during harvesting or with sub-

LIST OF COMMON AND SCIENTIFIC NAMES OF SPECIES MENTIONED IN THE TEXT

Common Name	Scientific Name and Authority
Balsam fir	*Abies balsamea* (L.) Mill.
Beech	*Fagus grandifolia* Ehrh.
Dogwood	*Cornus alternifolia* L.f.
Elderberry	*Sambucus canadensis* L.
Hobblebush	*Viburnum alnifolium* Marsh.
Mountain maple	*Acer spicatum* Lam.
Pin cherry	*Prunus pensylvanica* L.f.
Raspberry	*Rubus strigosus* Michx.
Red-berried elder	*Sambucus pubens* Michx.
Red maple	*Acer rubrum* L.
Striped maple	*Acer pensylvanicum* L.
Sugar maple	*Acer saccharum* Marsh.
Trembling aspen	*Populus tremuloides* Michx.
White ash	*Fraxinus americana* L.
White birch	*Betula papyrifera* Marsh.
Willow	*Salix* spp.
Spruce	*Picea* spp.
Yellow birch	*Betula alleghaniensis* Britton

sequent treatments as recommended by others (Marquis 1969; Lees 1975).

3. Care should be taken to avoid displacing the forest floor containing the seed banks from large areas. This is especially important if regeneration of large seeded species such as sugar maple and red maple is desired.

4. Light site preparation treatments which create a mineral soil seedbed without displacing the seed banks could be used to encourage regeneration of yellow birch. Patch scarification or treatments that mix the forest floor and mineral soil should give optimum results.

5. Harvesting should be timed to coincide with a good seed crop year. Alternatively, a good seed crop of yellow birch in the year before harvesting could be relied upon to provide some regeneration from the seed banks.

6. Further research should be conducted into the longevity of seeds in the seed banks under different field conditions for species such as yellow birch and white birch. More research is also needed to more clearly define the effects of disturbance on environmental factors that affect germination and survival.

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THE EFFECTS OF FULL-TREE AND TREE-LENGTH HARVESTS ON NATURAL REGENERATION AND SEEDLING MICROENVIRONMENTS

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INTRODUCTION

Background: In the forests of eastern Canada, advance regeneration is typically present in sufficient quantities in precut stands to partially or wholly restock cutovers, but current tree-length (TL) and full-tree (FT) harvesting practices destroy about one-half to three quarters of it, depending on the system used (Ruel 1988; Frisque *et al.* 1978). As a result, the natural regeneration currently surviving after harvests is frequently inadequate. Due to the high cost of artificially reforesting large areas, it may in some cases be desirable to reduce harvest destruction of natural regeneration in locations where it is thriving and abundant (Geier-Hayes 1987; Godin 1986). It has been shown that effective harvest management techniques may substantially reduce advance growth mortality during harvests without incurring additional costs, once the crews adjust to the reorganization of techniques (Begin 1986). Natural regeneration has the potential to become a more important component in reforestation if practices are fostered that minimize its destruction during harvests and increase its establishment after harvests.

In addition to the saving of planting costs, a potential reduction of the rotation period by as much as 10-30 years can be associated with preservation of vigorous advance regeneration (Begin 1986; Koroleff 1964).

Typically, studies of the effects of harvesting systems on regeneration have been conducted as surveys. Few have attempted direct comparisons of different harvesting systems, applied under controlled conditions in the same stand. Most previous studies have had a large sampling error because tally plots were not permanently marked before the harvest, so that their relocation after the harvest was only approximate (Zelazny 1987; Godin 1986).

In this study, the recommendations and observations of others were used extensively, in an effort to reduce these inaccuracies. The FT and TL systems are used as treatments side by side in the same mixed stands of spruce, fir, and intolerant hardwoods, at Deersdale, New Brunswick. This paper focuses on the effects observed shortly after highly mechanized harvests in which a Koehring feller-buncher (KFB) was used for felling, a stroke delimber for delimbing, and skidders for extraction, in both the FT and TL harvests. Since the study is still in progress, only preliminary interpretations are discussed here.

Plot centers were permanently marked in the precut stands, and all plant species present on the plots were tallied before and after the harvests. The surviving advance regeneration, ground surface disturbance, and slash conditions associated with each harvest system were therefore assessed in the same plots. Pending the completion of the study, natural regeneration losses will be addressed at two levels:

1) mortality of advance regeneration due to direct mechanical damage incurred during harvests by common FT and TL systems, and

2) later post-harvest losses of advance regeneration and new germinants, due to microenvironmental factors which result in desiccation, exposure, competition, or predation within the first year after harvest (Zelazny 1987).

The levels of ground surface disturbance by the two systems will be compared in detail. A key component affecting the habitat of seedlings is shade cast by slash and living residual plants (Edgren and Stein 1974); to address this, a detailed record was made of slash conditions and shading in the two treatments.

A microenvironmental study will be included in the summer of 1990. Ground surface temperatures, soil moisture levels in the seedling rooting zone, and the intensity of solar radiation penetrating to the litter surface through controlled slash loads of various depths will be continuously recorded.

In general, FT theoretically involves removal to roadside of the entire above-ground tree biomass before delimbing, while TL involves delimbing at the stump before removal of stems only to roadside. In practice, however, both FT and TL systems are highly variable in combinations of equipment and manpower employed in felling and extraction, with resultant wide variability in slash quantities and distribution, even within each system. Use of FT systems has greatly increased in the past decade in eastern Canada, replacing TL as the most widely used in the region (Gingras 1988). At this point, few studies have focused on the effects of FT systems on regeneration and site, and consequently little is known about the immediate or cumulative effects. An hypothesis which we will test after the completion of this study is that the differences in ground disturbance, slash quantities and slash distribution between the two systems will result in greatly differing seedbed properties and seedling microenvironments, and hence, to different establishment and survival of seedlings.

There is controversy in the literature about the effects of slash on regeneration; at some levels slash evidently favors competitive species such as raspberry (*Rubus* spp.) and pin cherry (*Prunus pensylvanica*) (Hall 1977), by providing a physical barrier to tree regeneration. However, other studies have shown that some slash loads provided shelter and increased the survival of advance regeneration and the establishment of new germinants (Geier-Hayes 1987; Titus 1985; Edgren and Stein 1974). Slash effects are manifold, and removal may have both short- and long-term effects. A concern is that the near total removal of nutrient-rich twigs and fine materials from cutovers with FT will result in progressive and serious soil nutrient depletion (Maliondo 1988), which may have immediate effects on residual trees (Mahendrappa, pers. comm.). Site- and species-specific research is required, to clarify the effects of slash and residue management practices in terms of site degradation and natural regeneration management (Edgren and Stein 1974).

In most cases, little consideration is given to the question of how harvest systems and management practices might affect advance regeneration, or affect the microenvironment and the seeding in of new germinants. On 5-year-old cutovers, 85% of spruce and fir seedlings were of advance origin, and only 1% from seed origin (Godin 1986; Weetman *et al.* 1973). Considering the potentially high numbers of seed scattered over cutovers during harvests (Horton 1965), this appears to indicate that high losses of new germinants are a common occurrence with current practices. Little natural filling-in of clearcuts by seed may be expected 1 year postharvest (Godin 1986; Frisque *et al.* 1978; Weetman *et al.* 1973), due to the short viability period of conifer seeds after dispersal (U.S. Forest Service 1974). To take advantage of viable seed, it is therefore necessary to provide conditions favoring new germinants immediately after harvests.

Assuming a considerable supply of seed, the low rate of establishment of new germinants probably stems largely from unfavorable microenvironmental conditions. Forest floor litter dries out rapidly when exposed to direct sun and summer heat, and therefore provides very poor seedbed (Place 1955). Surface temperatures from 49°C to 60°C may be lethal for 1st-year conifer seedlings depending on species, exposure time, and vigor of the individual (Hungerford and Babbitt 1987; Baker 1929), with 2 h exposure to 50°C, or an equivalent exposure, the limit for survival (Baker 1929). However, sublethal effects are also important because they severely decrease growth and increase susceptibility to further stresses (Spittlehouse and Stathers 1990). Common occurrences of potentially lethal high temperatures at the litter surface have been documented in many studies (Roberts and Dong 1990; Hungerford and Babbitt 1987; Place 1955).

Slash and microenvironment: A basic rationale behind these studies is that FT and TL harvests leave behind different seedling microenvironments. Shading is a key effect; the reduction of insolation, temperature extremes, moisture loss, and wind movement have had little study by their component parts, and evidently little work has been done to quantify the shading effects of different residues (Edgren and Stein 1974). Better regeneration success has been reported on shade protected sites than exposed sites in many forest types, even in coastal locations where environmental conditions are quite moderate (Edgren and Stein 1974).

Evidently the idea that tree seedlings are damaged by extremes of heat in the microclimate was unknown until the work of Heinrich Mayr in Germany in 1909 (Baker 1929). While air temperatures were never high enough to involve the entire plant in direct heat injury, the surface of the soil does become heated enough to form heat lesions on the stem within a few mm off ground level, particularly on the south and southwest sides of the plant. In severe cases, plants may be effectively girdled and fall over, but even in lesser cases, the injured area often serves as a portal of entry for pathogens and results in mortality (Baker 1929). On bright summer days, dangerously high temperatures may be reached on exposed soil surfaces throughout the temperate zone, at any altitudes at which the spruce type may be found (Baker 1929). Temperatures of 57°C to 61°C for 30 minutes, or 62°C to 65°C for 15 minutes, caused death of red pine (*Pinus resinosa*) and white pine (*Pinus strobus*) seedlings, and a general "safety limit" of 50°C for 2 h was suggested by Baker (1929) for conifer seedlings.

In New Brunswick, Place (1955) found that temperatures in seedbeds on level ground in the open were sustained above 50°C for 2 consecutive hours during a day of normal August weather, with peaks of about 60°C recorded. Small seedlings with roots that do not extend into the mineral soil dry out rapidly in such conditions. Temperatures in the shade, found in screen-shaded plots were in the order of 20°C cooler during the daily temperature peaks (Place 1955). Germination and early survival of conifer seedlings in general are greatly increased when some shade is provided, because of the reductions in surface temperature fluctuations and soil moisture losses (Geier-Hayes 1987; Arnott 1974; Place 1955). The conservation of moisture alone in the litter and the surface soil layers by ground shading might be of great benefit to small seedlings, even if they were not direct recipients of shade themselves. Slash and residues often provide the shade needed for seed germination and seedling establishment (Edgren and Stein 1974; Geier-Hayes 1987). The shade can reduce the level and duration of lethal soil surface temperatures, and slow the rate of evaporation from the soil surface. Ryker and Potter (1970) found in experiments with lath shelters that even unshaded areas close to shaded areas were substantially cooler (up to 10°C) than areas in the open. It appears

that best overall growth response probably occurs when the amount of shade decreases as the trees lose their succulence, become hardier, and increase their rooting depth. A further benefit of slash is that as it breaks down and returns its nutrients to the soil, its shading effect is reduced. This coincides with the natural requirement of most seedlings for increased light as they increase in size.

OBJECTIVES

1) To compare the mortality of advance regeneration immediately after harvests with representative FT and TL systems in mixed stands in New Brunswick.

2) To compare the first year survival of advance regeneration, and the numbers of new germinants established the first year in the seedbed conditions occurring in each treatment.

3) To compare slash conditions resulting from these harvest systems, and to relate survival of advance regeneration and new germinants to a series of slash levels.

4) To establish standard curves at the litter surface for temperatures, light intensities, and soil moisture losses in the seedling rooting zone for a range of controlled slash loads, and to relate seedling survival to these parameters.

METHODS

Experimental Design:

In a relatively uniform area of mature mixedwood forest at Deersdale, two harvest blocks, each with one replication of the two levels of the treatment (FT with feller-buncher and skidders, and TL with feller-buncher and skidders) were established. These systems are representative of highly mechanized harvesting methods in eastern Canada. The treatments were laid out side by side in each block, in strips 100 m wide, FT alternating with TL. Sample plots were installed along parallel transects established perpendicular to the slope and the direction of travel of the harvest equipment. In each replication, 25 circular 5-m permanent plots were installed, a total of 50 plots per treatment. The centers were permanently marked before the harvest, with painted wooden stakes driven just below flush with the surface, and referenced with painted witness stumps. A three-stage sampling scheme is partly completed, and is described below.

Stage 1

Preharvest measurements: Within the circular plots, all advance regeneration and shrubs were tallied by height classes: 1-10 cm, 11-30 cm, 31-70 cm, 71-130 cm, and >130 cm (<1 cm dbh), and in 2-cm dbh classes (>1cm dbh). Percent plot area cover by each species of ericaceous and herbaceous species was recorded. Overstory prism tallies were performed in every other plot, to provide an indication of the variability of the overstory. Soil pits were dug and the soil profiles described; drainage classes determined; and treatment units identified using the N.B. site classification system (NBFRAC 1985).

Stage 2

Postharvest measurements: Immediately after the harvest, the plots were again tallied, and all surviving advance regeneration and vegetation recorded. The immediate before-and-after harvest sampling design permits comparisons of advance growth damage and mortality directly associated with each harvest treatment. Factors affecting seedbed potential, such as mineral soil exposure, litter disturbance, the presence of wet sphagnum mosses, feather mosses, water, well rotted wood, slash depth and distribution, shading, and litter layer (L-F-H) thicknesses were recorded. Data were collected on microtopography, slope, and aspect.

Stage 3

First year survival measurements: The plots will be sampled again at the end of one full growing season (spring 1990), to compare the amount of mortality since the harvest in each treatment, due to desiccation and exposure associated with the microenvironments left by each treatment (Zelazny 1987).

Data analysis: There are two blocks, with one factor (harvest system) at two levels (FT and TL). The two levels of the factor will be compared with respect to the following variables: numbers of advance stems before and after harvest, mortality due to harvesting, slash depth and plot coverage, abundance and type of non-commercial species before and after harvest, numbers of new germinants by species, and ground disturbance. Germination and mortality of new seedlings will be compared by harvest system, seedbed material, slash levels, and microtopography class. The null hypothesis that no real differences exist between means of variables in each treatment will be tested with analysis of variance.

Preliminary results: Figures 1 and 2 show the abundance of some of the important species in the two treatments before harvesting. The preharvest distributions of species and numbers of stems were fairly even for red maple (rM, *Acer rubrum*) and white birch (wB, *Betula papyrifera*). A large difference occurred between treatments in numbers of preharvest balsam fir (bF, *Abies balsamea*) in the smallest size classes. As shown in Figures 1 and 2, after harvesting, the smallest size classes were essentially obliterated by the harvests. More rM and wB were present in the FT plots than the TL plots, before and after harvesting.

Comparison of Figures 1 and 2 suggests that, with the exception of the 31-70 cm bF stems and all of the raspberry (*Rubus* spp.) size classes, the actual mortality was relatively uniform in the two treatments. The statistical significance of these results has not yet been assessed. The differences in survival of the bF and *Rubus* could have a considerable effect on the sites. Figures 3, 4, 5, and 6 show the mortality patterns for spruce (S, *Picea* spp.), bF, rM, and wB. A striking similarity is evident in the four graphs; in nearly every case, the smallest size classes were totally eliminated and mortality progressively decreased with increasing size class, then increased again for the largest classes (dbh between 1 and 3 cm). It appears that, in general, the smallest, succulent stems do not survive harvesting; probably they are crushed or swept away during the passage of machinery or their loads. This suggests that the smallest size classes could not be considered a source of regeneration after harvests. The largest woody stems are perhaps subject to breakage, while the intermediate sizes are small enough to escape breakage and resilient enough to recover from harvesting disturbance. The large apparent difference in mortality of the largest size class of wB stems is due to small sample size (only 6 stems in TL and 3 in FT). Since the statistical significance of the figures has not yet been determined, it is difficult to draw any further conclusions from these graphs.

Figure 7 indicates the distribution of slash depth classes between the two treatments. It is evident that more of the FT plots had slash loads in the shallowest depth classes, while the TL plots received a broader range of slash depths. These results are apparently related to the highly mechanized nature of the operations. In the case of the TL system, much of the slash was dumped in long, fairly even windrows as the stroke delimber followed the KFB along the site. The windrows alternated with strips of shallow slash cover, because the machine operators dumped the majority of the slash to one side as they moved along the harvest blocks, cutting in strips. This technique tended to produce regions of two extremes: deeper slash which was probably too deep to favor seedling growth or germination,

Figure 1

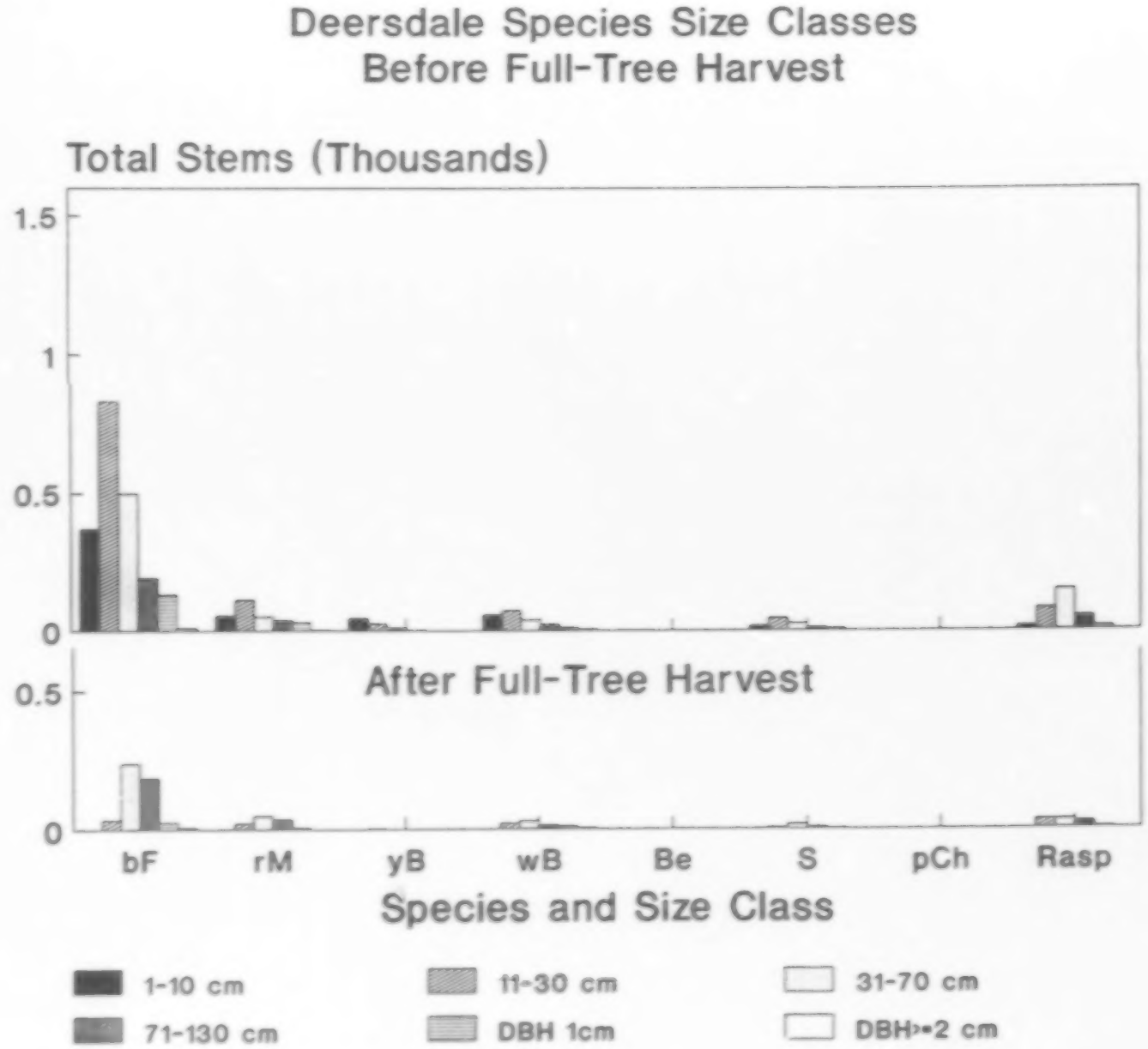
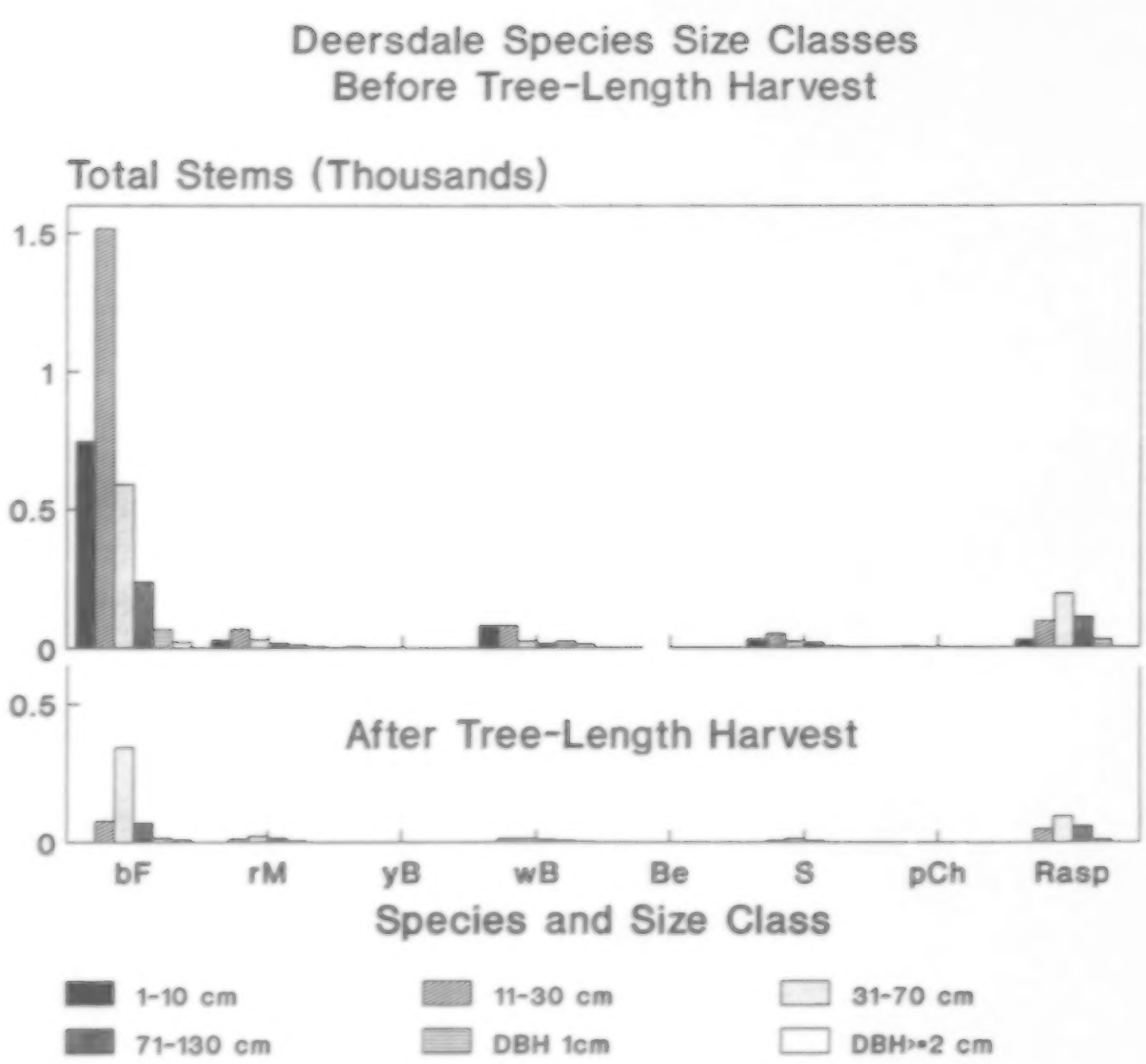

Deersdale Species Size Classes
Before Full-Tree Harvest
Total Stems (Thousands)
1.5
1
0.5
0
After Full-Tree Harvest
0.5
0
bF
rM
yB
wB
Be
S
pCh
Rasp
Species and Size Class
1-10 cm
11-30 cm
31-70 cm
71-130 cm
DBH 1cm
DBH>=2 cm

Figure 2


Deersdale Species Size Classes
Before Tree-Length Harvest
Total Stems (Thousands)
1.5
1
0.5
0
0.5
0
After Tree-Length Harvest
bF
rM
yB
wB
Be
S
pCh
Rasp
Species and Size Class
1-10 cm
11-30 cm
31-70 cm
71-130 cm
DBH 1cm
DBH>=2 cm

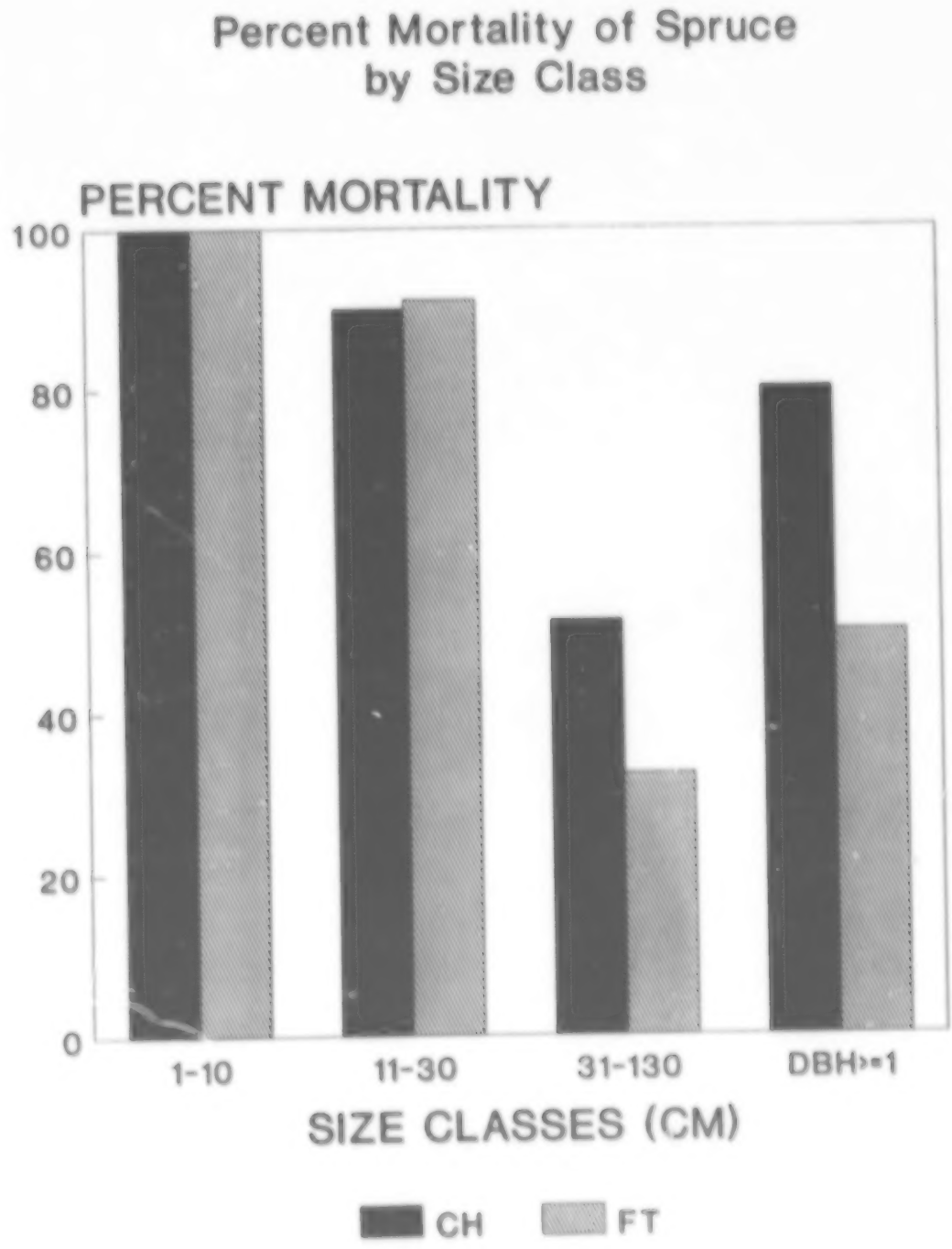

Percent Mortality of Spruce
by Size Class
PERCENT MORTALITY
100
80
60
40
20
0
1-10
11-30
31-130
DBH>=1
SIZE CLASSES (CM)
CH
FT

Figure 3

Percent Mortality of Balsam fir by Size Class

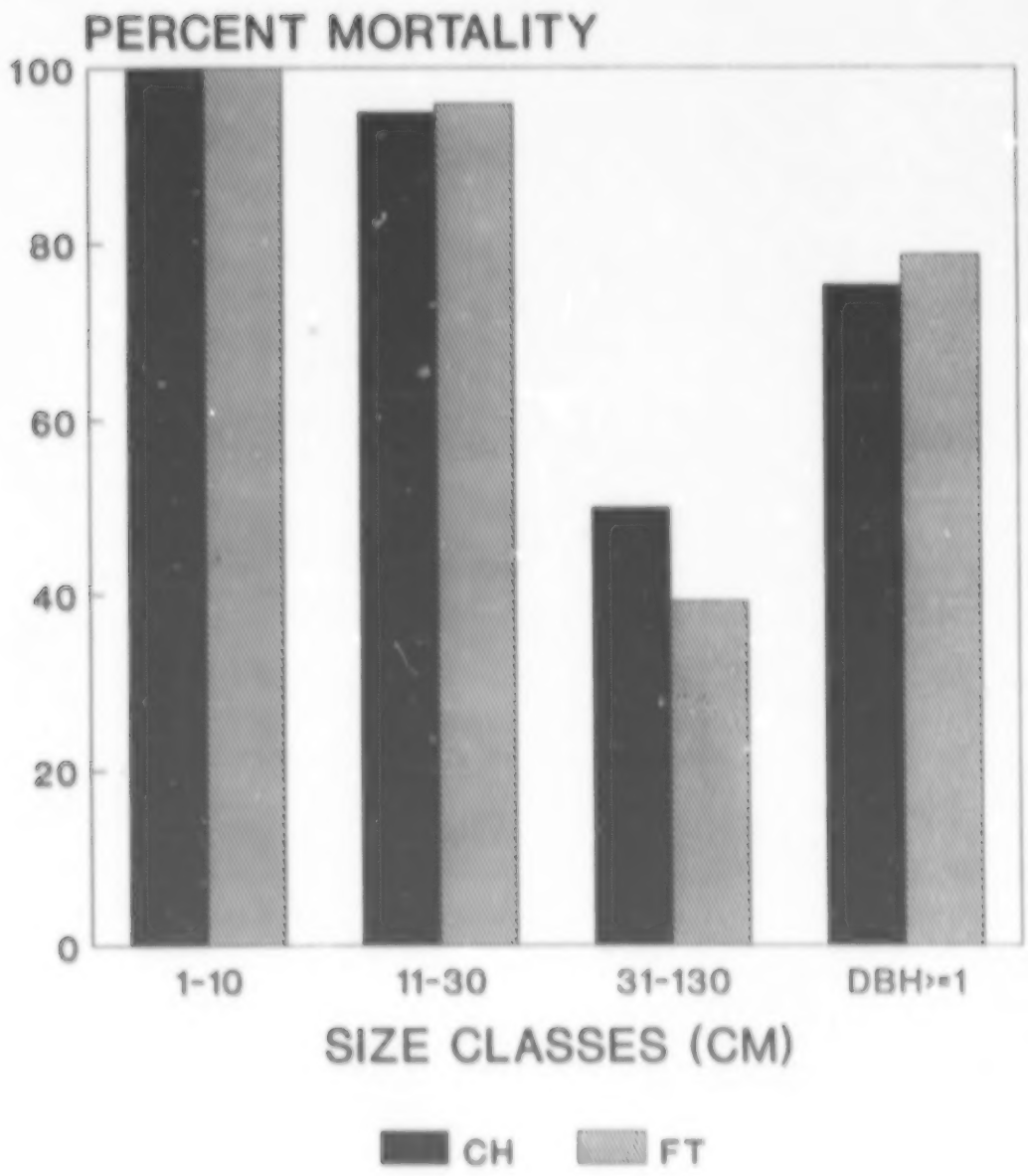


Figure 4

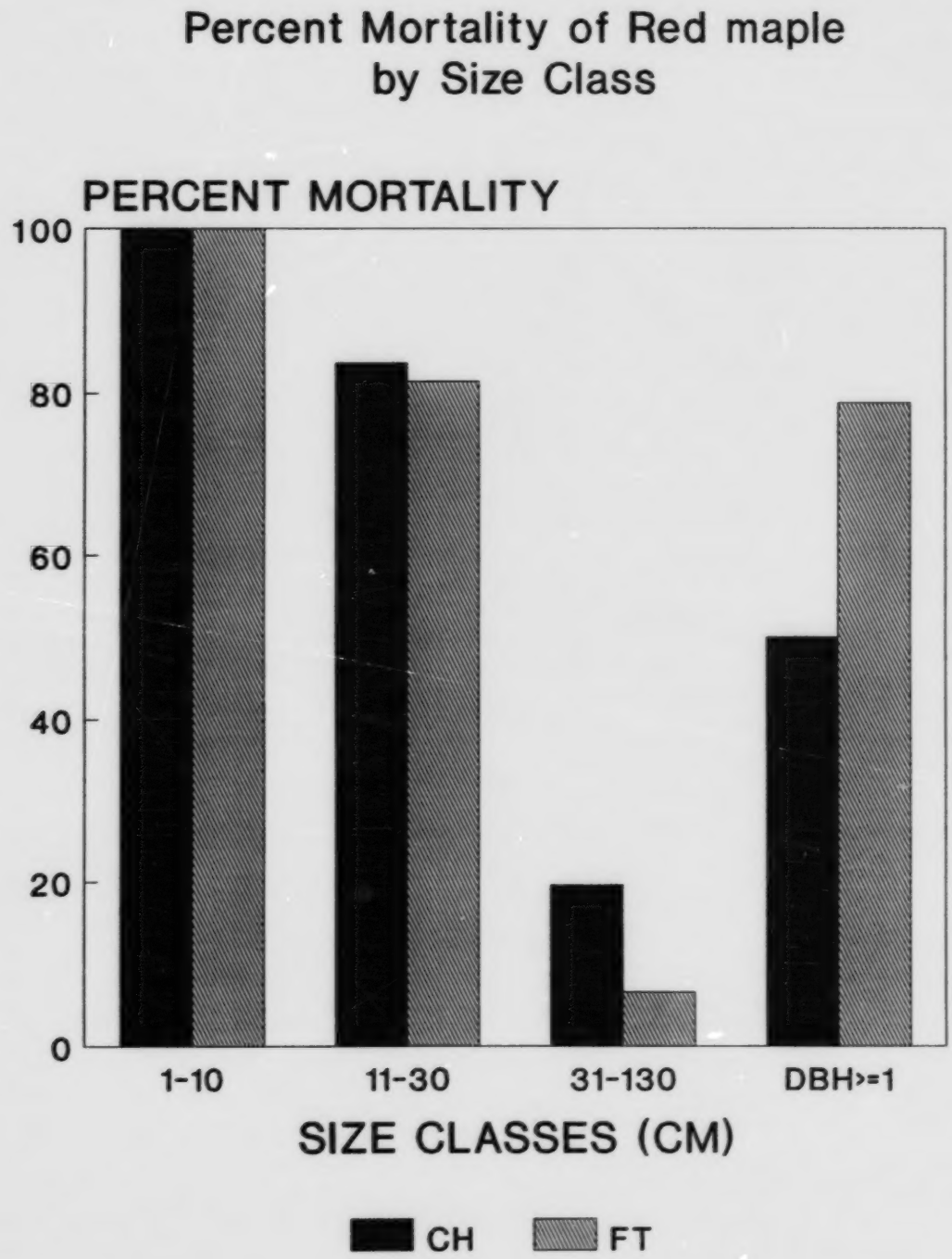

Percent Mortality of Red maple
by Size Class
PERCENT MORTALITY
100
80
60
40
20
0
1-10
11-30
31-130
DBH>=1
SIZE CLASSES (CM)
CH
FT

Figure 5

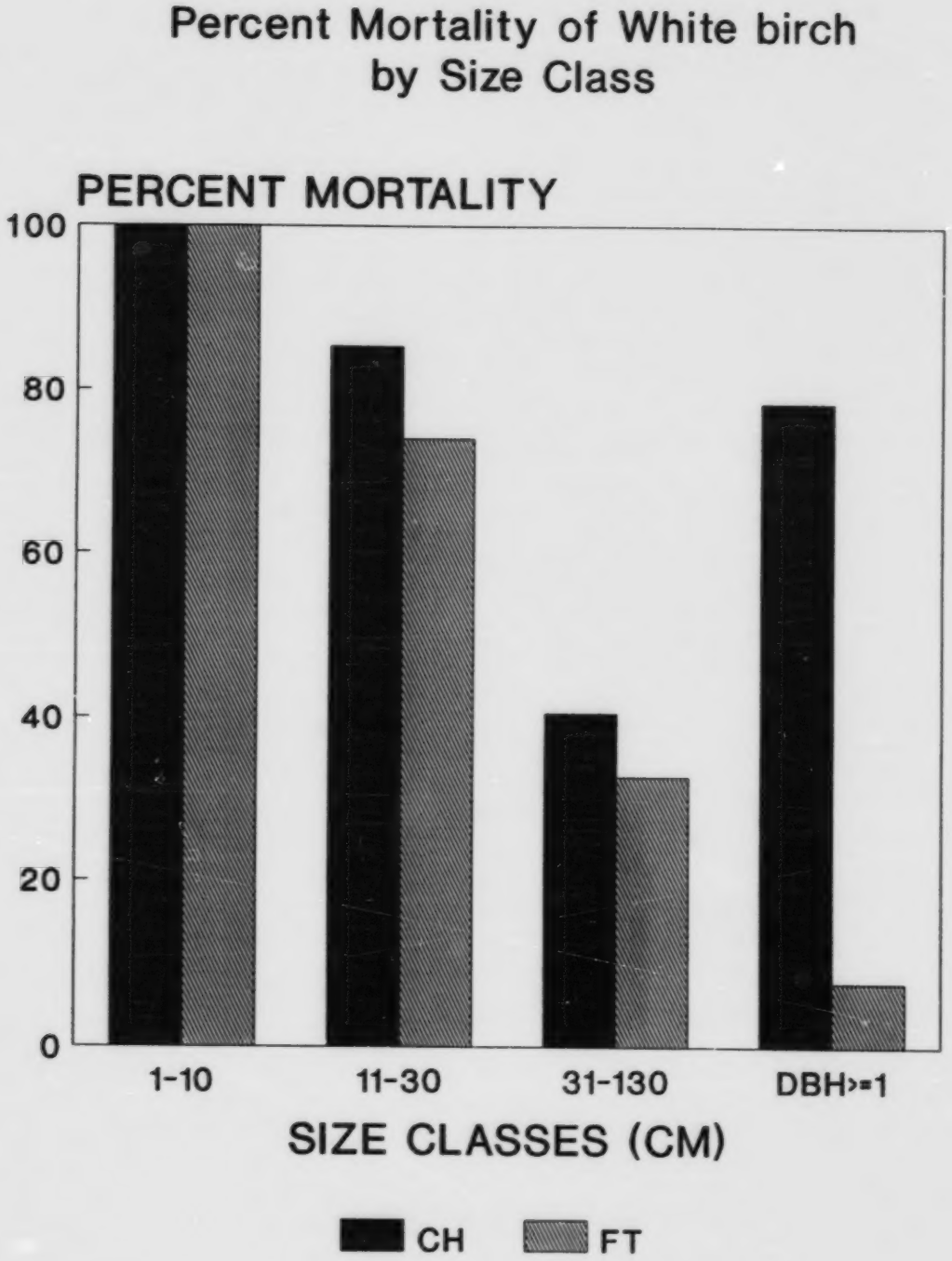

Percent Mortality of White birch
by Size Class
PERCENT MORTALITY
100
80
60
40
20
0
1-10
11-30
31-130
DBH>=1
SIZE CLASSES (CM)
CH
FT

Figure 6

Deersdale Slash Depth Classes
Full-tree and Tree-length Harvests

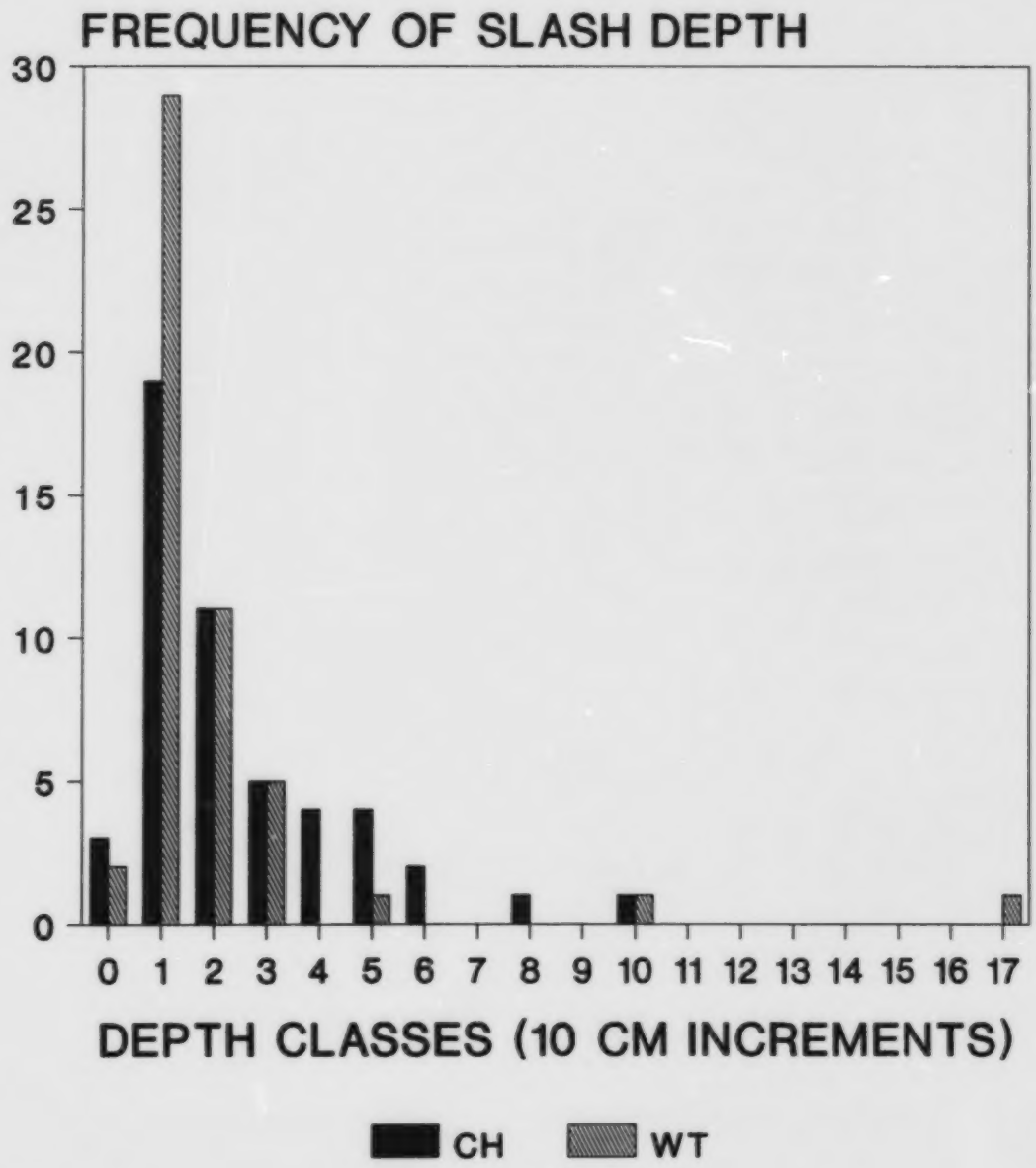


Figure 7

Figure 8

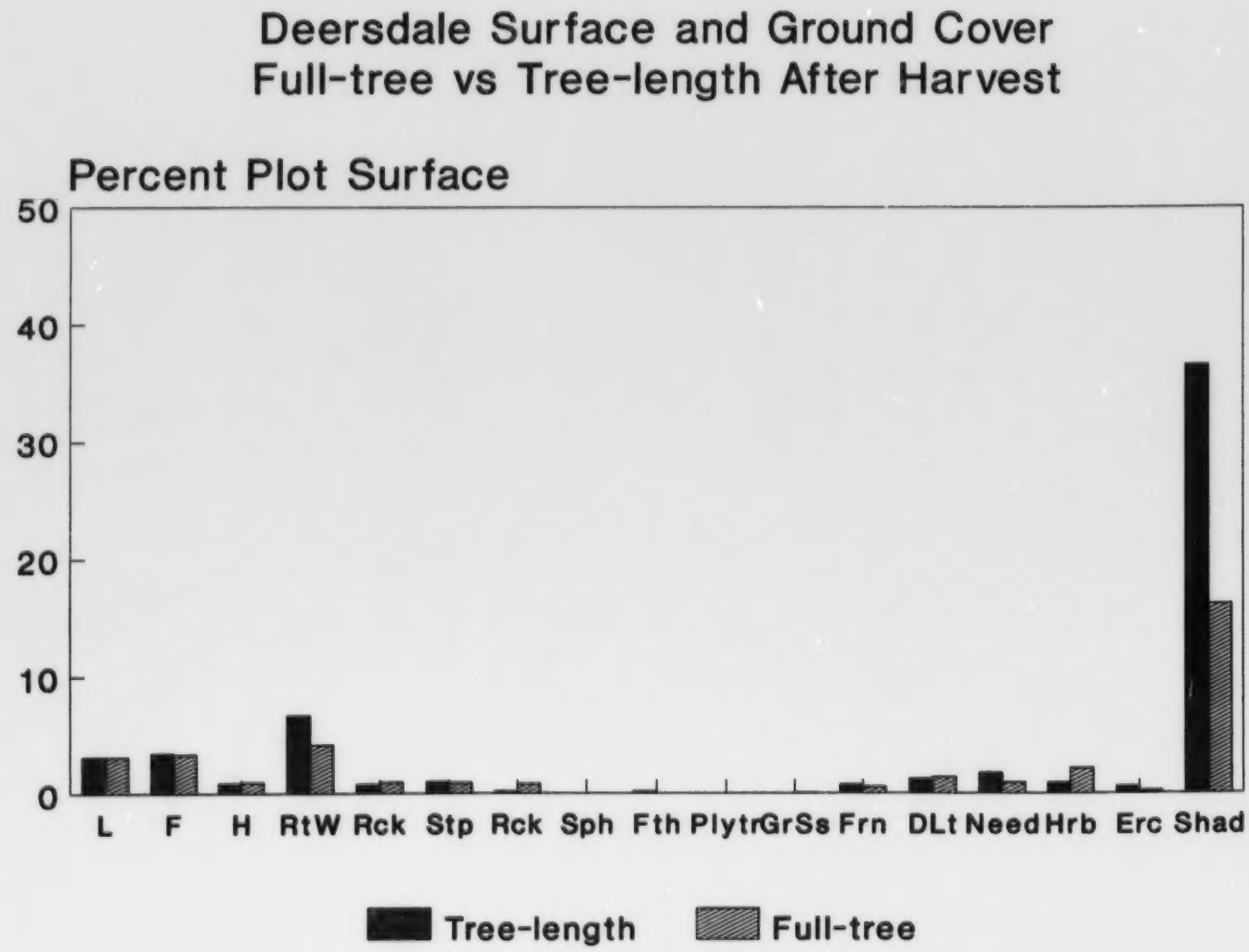

Deersdale Surface and Ground Cover
Full-tree vs Tree-length After Harvest
Percent Plot Surface
50
40
30
20
10
0
L
F
H
RtW
Rck
Stp
Rck
Sph
Fth
Plytr
GrSs
Frn
DLt
Need
Hrb
Erc
Shad
Tree-length
Full-tree

Figure 9

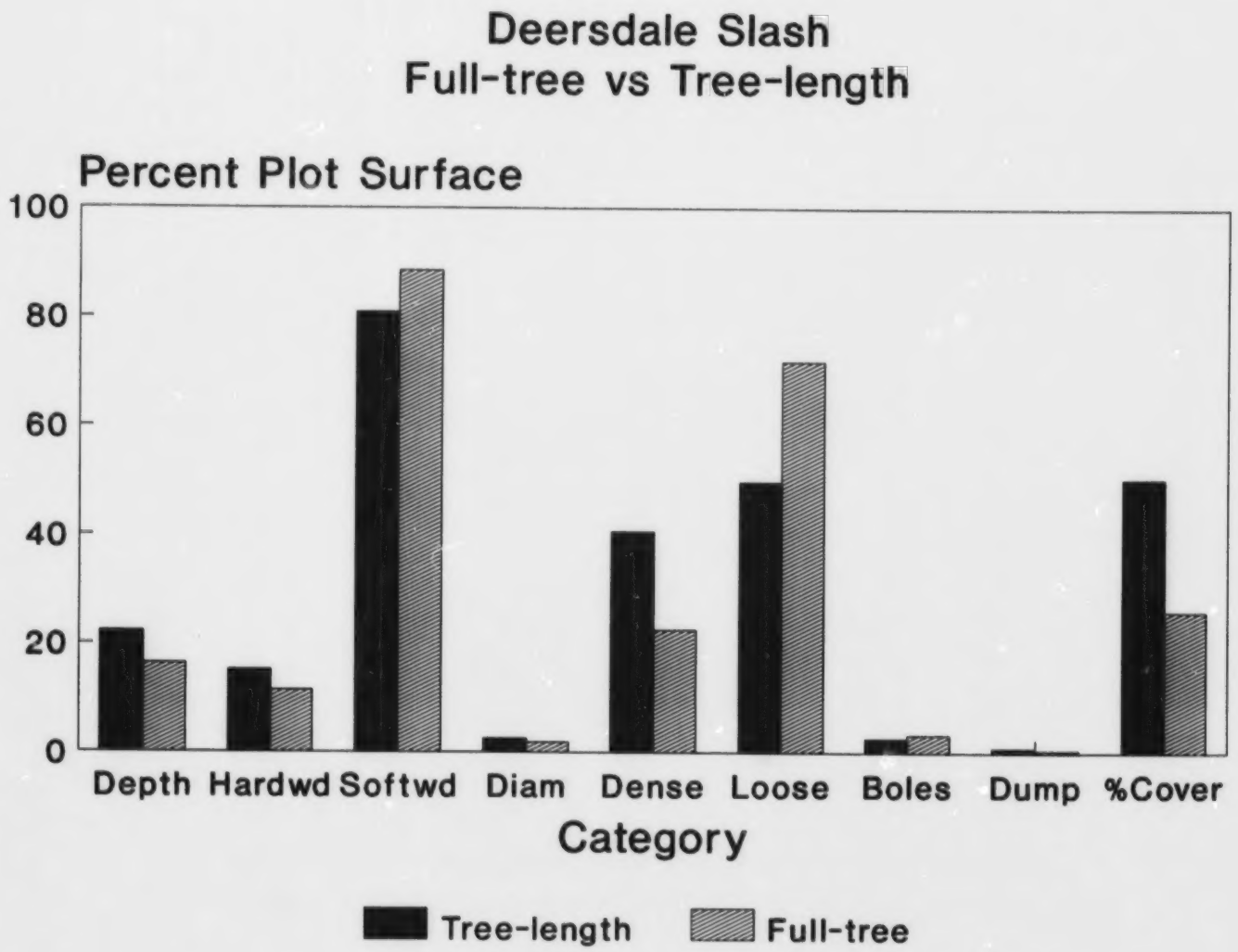
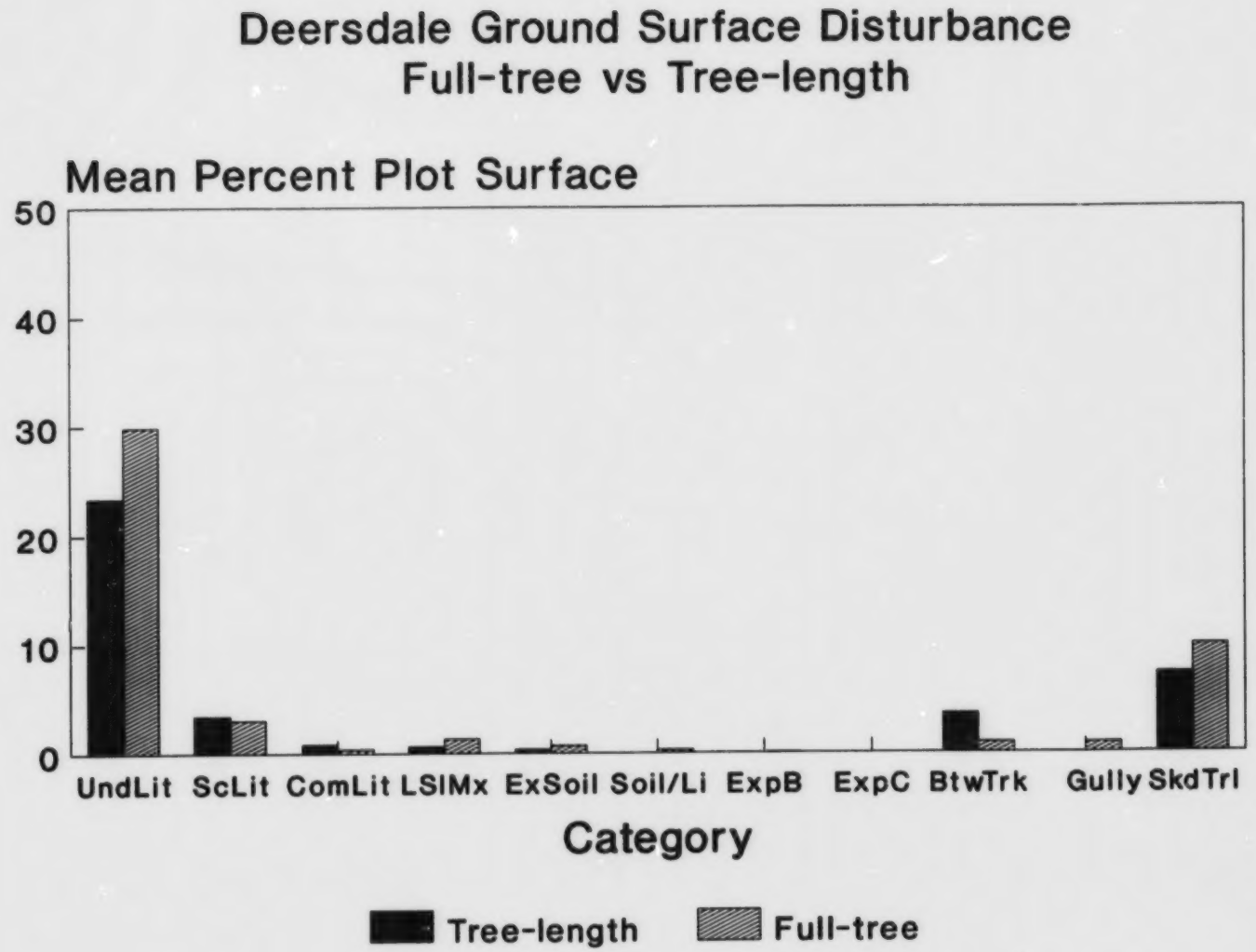

Deersdale Slash
Full-tree vs Tree-length
Percent Plot Surface
100
80
60
40
20
0
Depth
Hardwd
Softwd
Diam
Dense
Loose
Boles
Dump
%Cover
Category
Tree-length
Full-tree

Figure 10


Deersdale Ground Surface Disturbance
Full-tree vs Tree-length
Mean Percent Plot Surface
50
40
30
20
10
0
UndLit
ScLit
ComLit
LSlMx
ExSoil
Soil/Li
ExpB
ExpC
BtwTrk
Gully
SkdTrl
Category
Tree-length
Full-tree

alternating with relatively exposed surfaces offering little shelter. However, very little of the TL area was as devoid of slash cover as the FT plots, many of which were swept totally bare, leaving only woody debris and litter. Overall, visual inspection of the site suggested that considerably more surviving vegetation was present in the TL plots, although it is possible that many of the severely defoliated plants in the FT plots were not killed, and may recover. It is the authors' opinion that much of the apparent damage was done by the sweeping effect of the FT/skidder harvest, as the trees were dragged like large brushes through the regeneration. Slash appeared to offer some protection against crushing and abrasion to the smaller seedlings during machine passage, since equipment and loads passed over slash rather than the regeneration.

Little difference was evident between the two treatments in most categories of the surface and ground cover conditions (Figure 8). The only prominent difference appears in the percent plot surface shaded category, in which the TL plots showed more than double the shaded surface. This is in agreement with the percent slash cover over plot surfaces as shown in Figure 9. Also notable in Figure 9 is a tendency for FT plots to have a greater amount of "loose" slash, while TL plots had more "dense" slash. These estimates were subjectively assessed, on a "best description" basis of the slash conditions over a plot.

In Figure 10, the ground surface disturbance conditions are shown. For the most part, the two treatments do not appear to differ greatly in the categories shown. A possible difference is indicated in the undisturbed litter category between treatments; less litter disturbance may indicate less potential seedbed in the FT treatment.

CONCLUSIONS

Until statistical analyses are completed, only tentative interpretations can be offered, based on the obvious trends, and on first-hand assessments of the site during and after harvesting. A consistent trend in the pattern of mortality was evident in S, bF, rM, and wB, for both FT and TL treatments. The intermediate size classes showed high survival rates, while the smallest and largest size classes experienced high mortality.

Pronounced slash cover and density differences, along with shade differences, were evident between FT and TL treatments. This may result in differences in microenvironmental factors, and therefore differences in desiccation, exposure, competition, or predation within the first year after harvest.

Severe defoliation of understory shrubs and trees was observed with the mechanized FT summer harvest with skidders. It is possible that many of these will regenerate new foliage by the following season. However, it is felt that the defoliation still contributed to increased exposure of the smaller regeneration, and greater extremes in the microclimate.

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Appendix A Lists of Species in Text and Graphs

Abbreviation	Common Name	Scientific Name
bF	Balsam fir	*Abies balsamea* (L.) Mill.
rM	Red maple	*Acer rubrum* L.
yB	Yellow birch	*Betula allegheniensis* Britton
wB	White birch	*Betula papyrifera* Marsh.
Be	Beech	*Fagus grandidentata* Ehrh.
S	Spruce	*Picea* spp.
pCh	Pin cherry	*Prunus pensylvanica* L.f.
Rasp	Raspberry	*Rubus* spp.

NATURAL SEED REGENERATION OF BLACK SPRUCE (*PICEA MARIANA*) STANDS IN THE QUEBEC BOREAL FOREST

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ABSTRACT

Natural fires are an important ecological factor in the boreal forest. After fire, black spruce behaves like jack pine. Our results show a prompt recolonisation of burned sites. The majority of new seedlings were established within three years after fire. These data differ from other works where a delay in recolonisation has been noted. For comparison purposes, a second project has been conducted in black spruce strip cutting to determine the establishment period of black spruce seedlings under a continuous seed supply. Quite surprisingly, the establishment period was similar to the natural burned site, showing a prompt and brief installation after cutting.

INTRODUCTION

Recent regeneration surveys in Quebec have shown that 94 % of black spruce (*Picea mariana* (Mill.) B.S.P.) advanced growth are layers (Doucet 1988). Therefore, sexual reproduction of black spruce is a phenomenon that does not seem important enough to be taken into account. But, is the mother tree itself a layer? An easy way to check the origin of a stand is to elaborate the age structure of the trees. Layer origin stands typically show an uneven age structure which characterizes a long period of establishment associated to vegetative reproduction (Légère and Payette 1981; Horton and Groot 1988; Lussier *et al.* 1991).

Origin of black spruce stands

In the boreal forest north of Lac St-Jean (Figure 1), we investigated the origin of many well stocked virgin black spruce stands. The results show that the great majority of commercial virgin black spruce stands are even-aged (Figure 2). This type of age structure indicates a punctual installation which is incompatible with layer origin stands. So, if the layer mother tree is not itself a layer, what is its origin?

Clues can be found in age structure and even in the soil. First, age structure reveals that punctual establishment was preceeded by a complete elimination of the pre-existing stand, since there is no tree older than the age of the narrow cohort, and we know that black spruce can live up to 250 years (Heinselman 1965). Second, many bits of charcoal are found in the organic horizon, near the mineral soil. The data suggest that fire preceeded the establishment of the stand (Gagnon 1989). Historical data from lake sediments confirm the recurrence of fire since the apparition of trees in the region, nine to ten thousand years ago (Gagnon 1988). Today, fire is recognized as one of the major ecological factors affecting the boreal forest. The whole ecosystem evolved in response to fire and is therefore called a fire-dependent ecosystem (Heinselman 1973, 1981). After fire, the only way black spruce can regenerate is by seed, and thus we can conclude that the layer mother tree in a virgin black spruce stand comes from seed

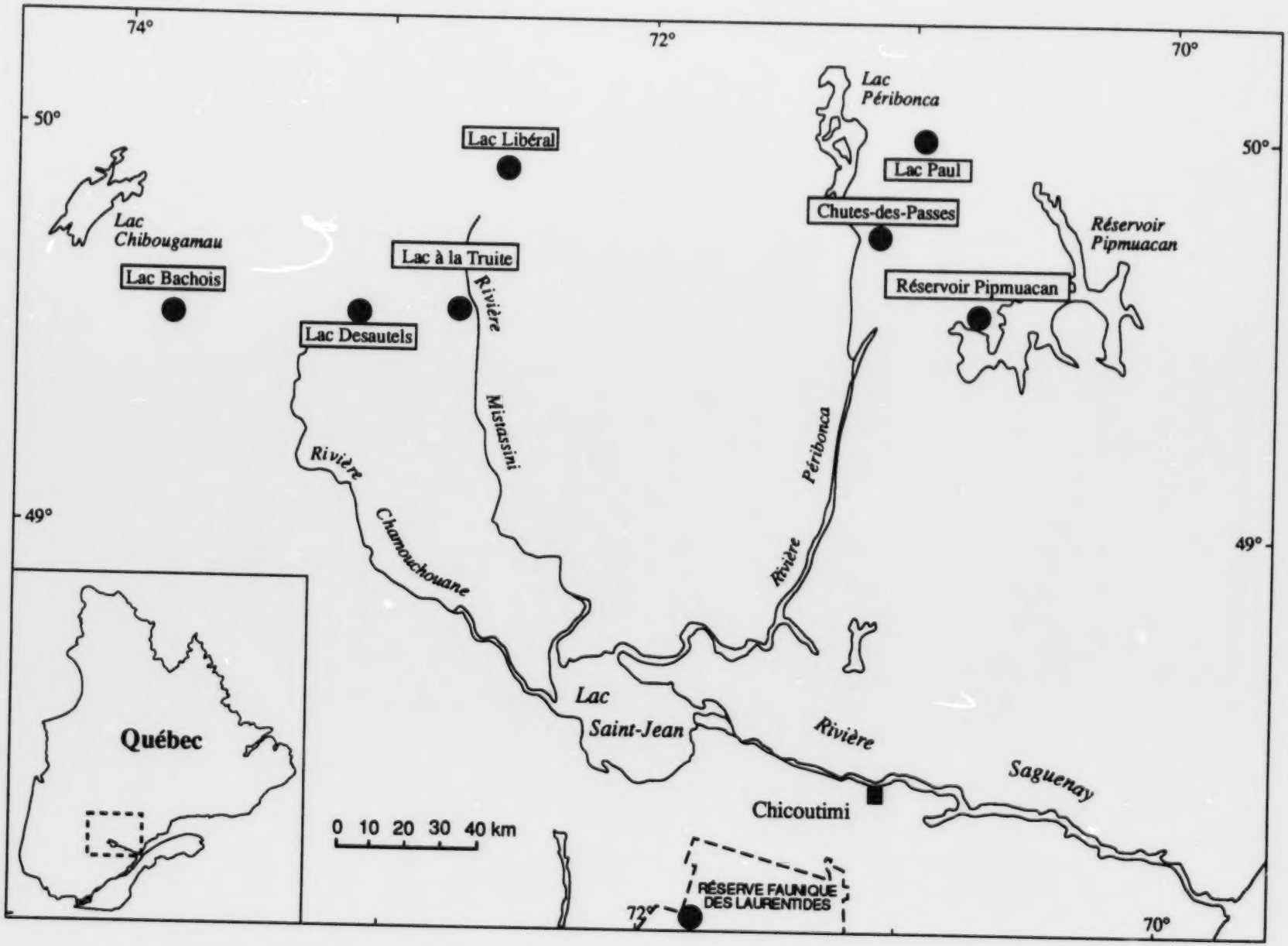

Figure 1. Studied regions.

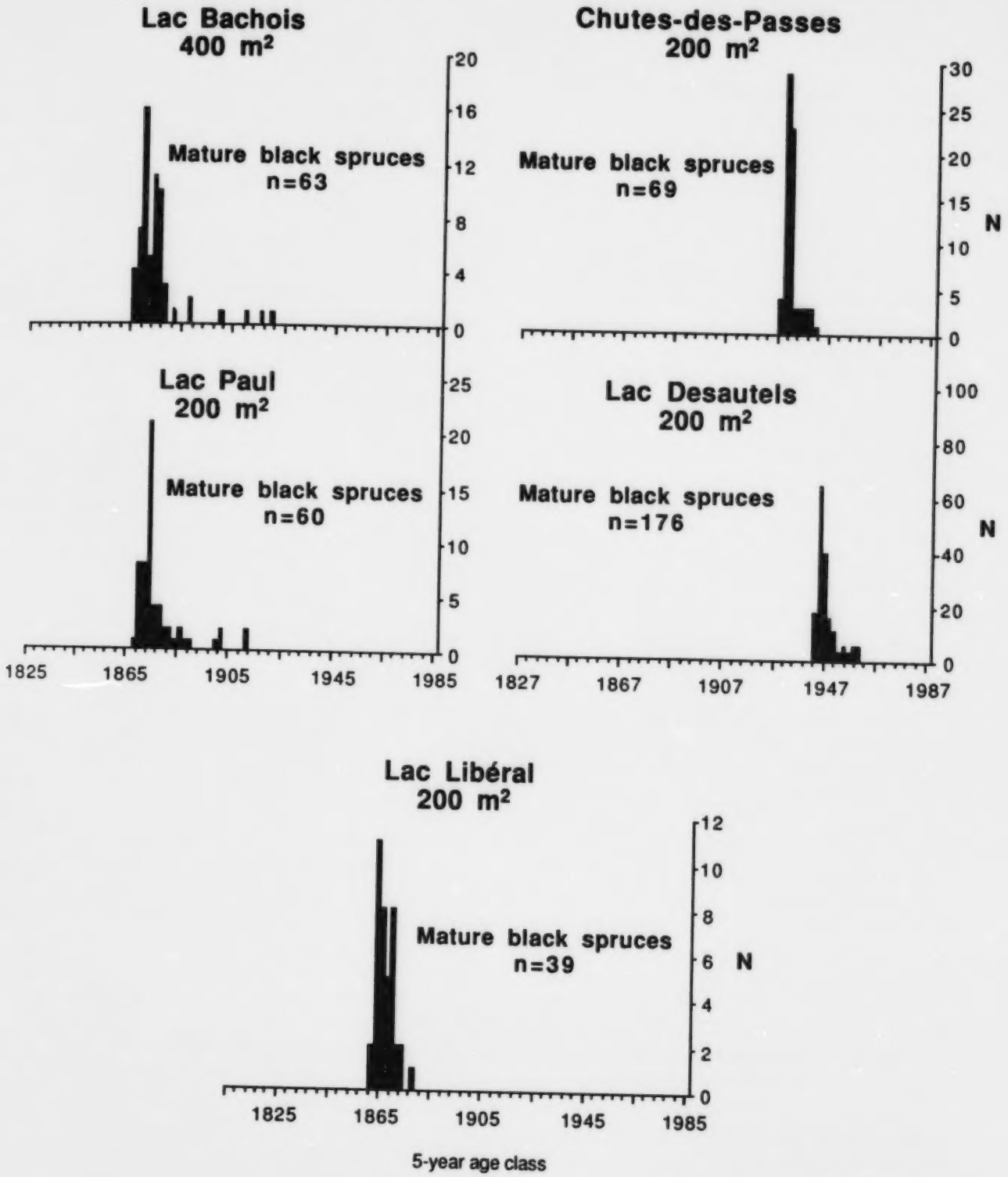

Fig. 2. Age structures of virgin black spruce stands north of Lake St-Jean, Quebec. These age structures must be reinterpreted in light of new data.

and not from layering. Appearances are sometimes deceptive.

But how can black spruce regenerate after fire? In short, it behaves like jack pine (*Pinus banksiana* Lamb.). Black spruce seed source, unlike other species, does not lie in the soil. It is found rather in clusters at the top of trees killed by fire (Nickerson 1958). Seeds are protected by semi-serotinous cones and can survive extreme fire heat. Fire causes the cones to open and allows seeds to be dispersed.

Establishment period

After fire

There is some controversy about the establishment of black spruce seedlings after fire. Some authors believe the maximum establishment period to occur 5 to 15 years after fire (MacArthur 1964; Gagnon 1973; Lieffers 1986, Morneau and Payette 1989) while others believe there is no time lag (Heinselman 1957; Ahlgren 1974; Carleton 1985). A recent study done by St-Pierre (1990) 6 years after a fire helps to clarify the situation. Results show that black spruce establishment after fire is not delayed and seems to be completed quickly, at least for the first 5 years, in less than 3 years after the fire (Figure 3). These data are close to being confirmed by another exhaustive demographic study conducted in the region, where installation and mortality of seedlings have been followed each year since the fire (Figure 4). A pseudo-delay in black spruce establishment after fire was noted when data were collected many years after fire (Figure 5), as in Hatcher's work (1963) and in a recent study done by Morneau and Payette (1989) (Figure 6). As the date of sampling after fire is delayed, the year of maximum establishment shifts from left to right in the age structure. Older stands systematically show a longer delay before maximum seedling establishment. These pseudo-delays can be explained by the difficulty in sampling all annual rings at the tree base, especially the first ones, since sampling height does not necessarily correspond to root collar, and by the fact that tree rings may sometimes be missing.

After strip cutting

Strip cutting is an application based on sexual reproduction used in natural regeneration management. The aim of this method is to favor the establishment of new seedlings by maintaining a living seed source near the harvested site. The efficiency of the method must be measured by evaluating the number of new seedlings originating from sexual reproduction. On dry, undisturbed upland sites, the establishment of new seedlings is usually poor. On mesic-wet sites, the establishment is better but variable. It seems difficult to predict the number of new seedlings; site characterictics seem to account for 50% of the observed variability (Laroche 1988). Quite surprisingly, in spite of a continuous and abundant seed supply, the establishment period is brief and follows the same pattern as after a fire (Figure 7). The receptivity of the seed bed appears to change rapidly. We still have a lot of work to do in order to discover the basic causes of this phenomenon. Anyhow, strip cutting is a partial solution because leave strips must be regenerated by using another method, like planting or protecting advanced regeneration during logging. Direct seeding is not a common practice in Quebec since most experiments have shown poor results (Parent 1987).

CONCLUSION

The great majority of virgin black spruce stands actually harvested in Quebec come from sexual reproduction, not from layering. Age structures obtained from old trees are poor representations of reality. Some results (Figure 2) must be reinterpreted in the light of new data (Figures 3, 4). Naturally, without man's intervention, sexual reproduction is an efficient method. But today, as in the past, not all methods of regeneration based on sexual

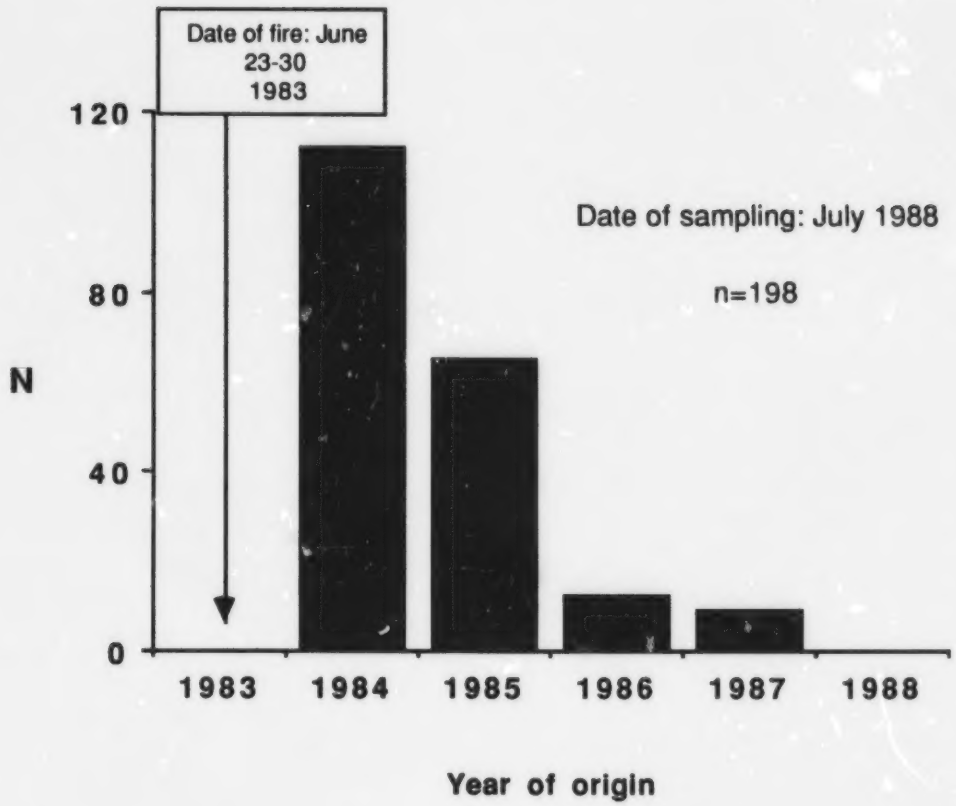

Fig. 3. Age structure of black spruce regeneration after fire, Lac Desautels, Québec.

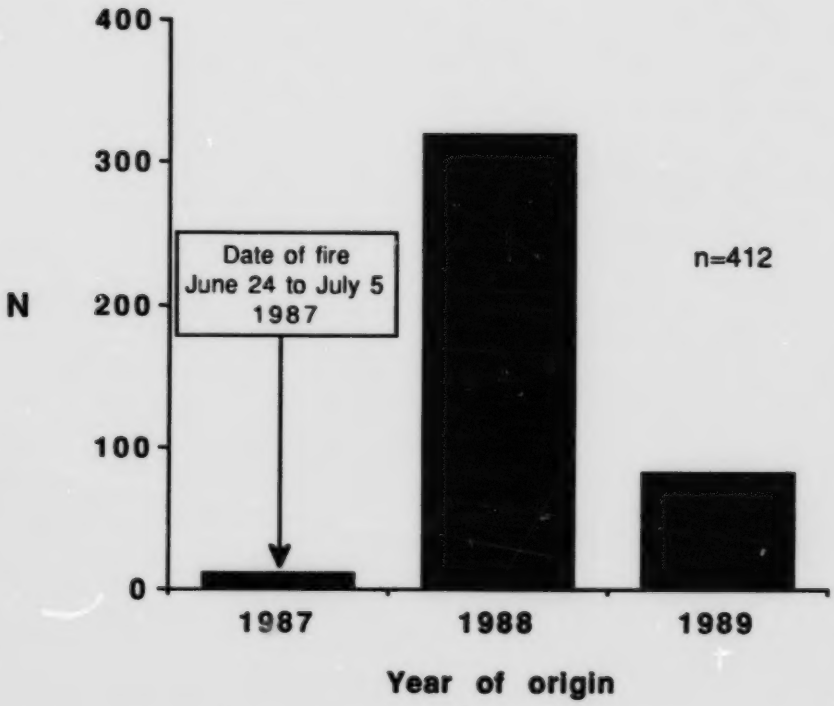

Fig. 4. Age structure of black spruce regeneration after fire, Réservoir Pipmuacan, Québec (3 years sampling, the study is still under way).

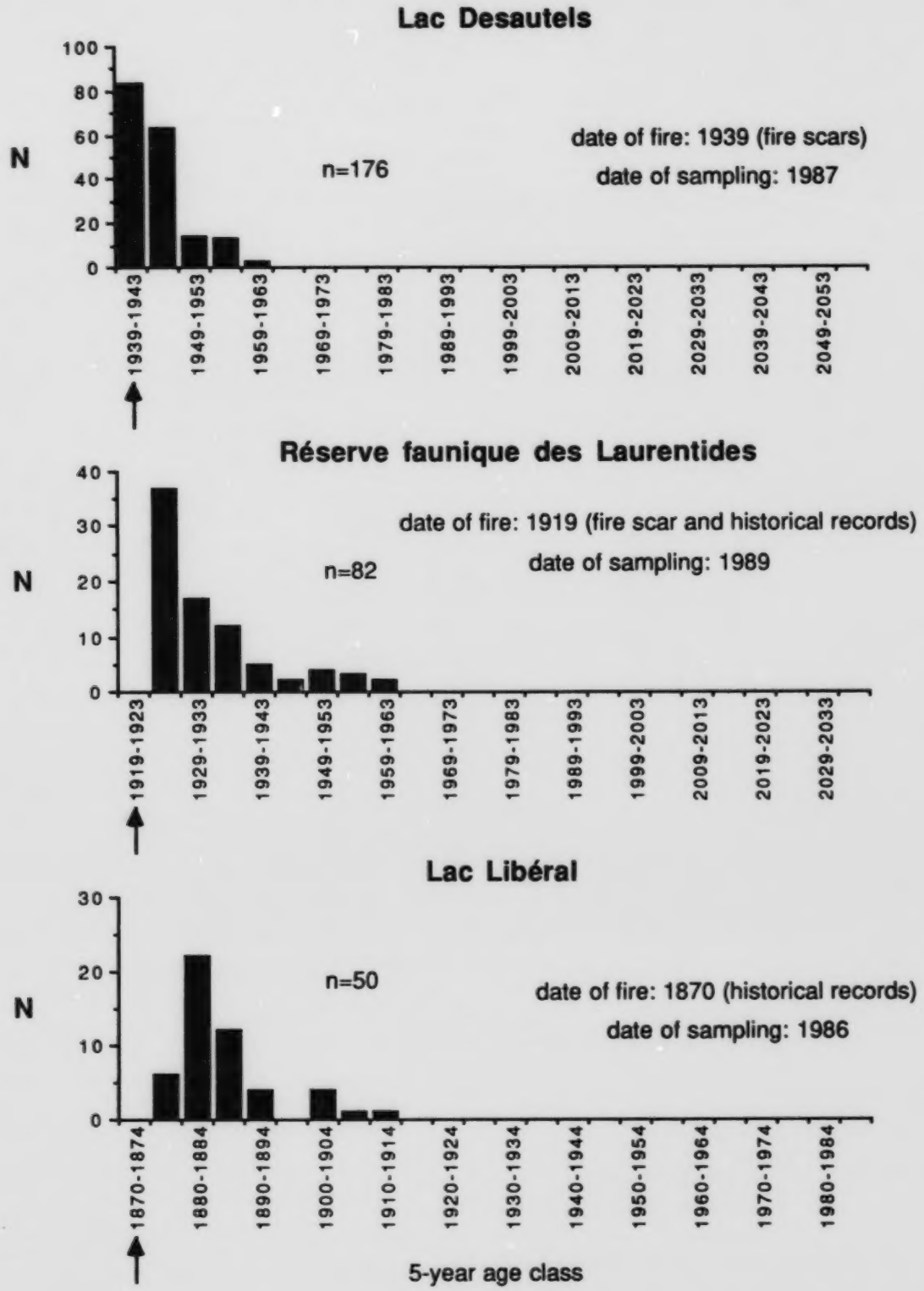

Fig. 5. Age structures of black spruce stands showing the shift of maximum establishment from left to right as stand are getting older.

→ fire date

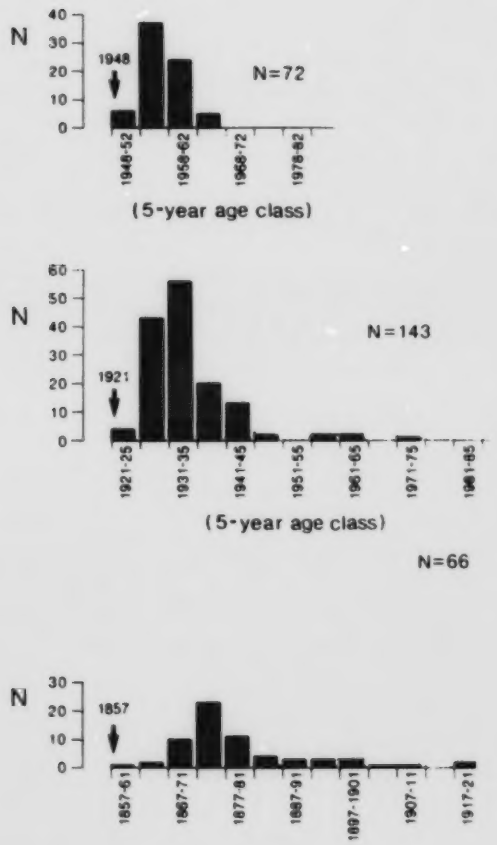

Fig. 6. Age structures of black spruce stands (modified from Morneau and Payette, 1989).

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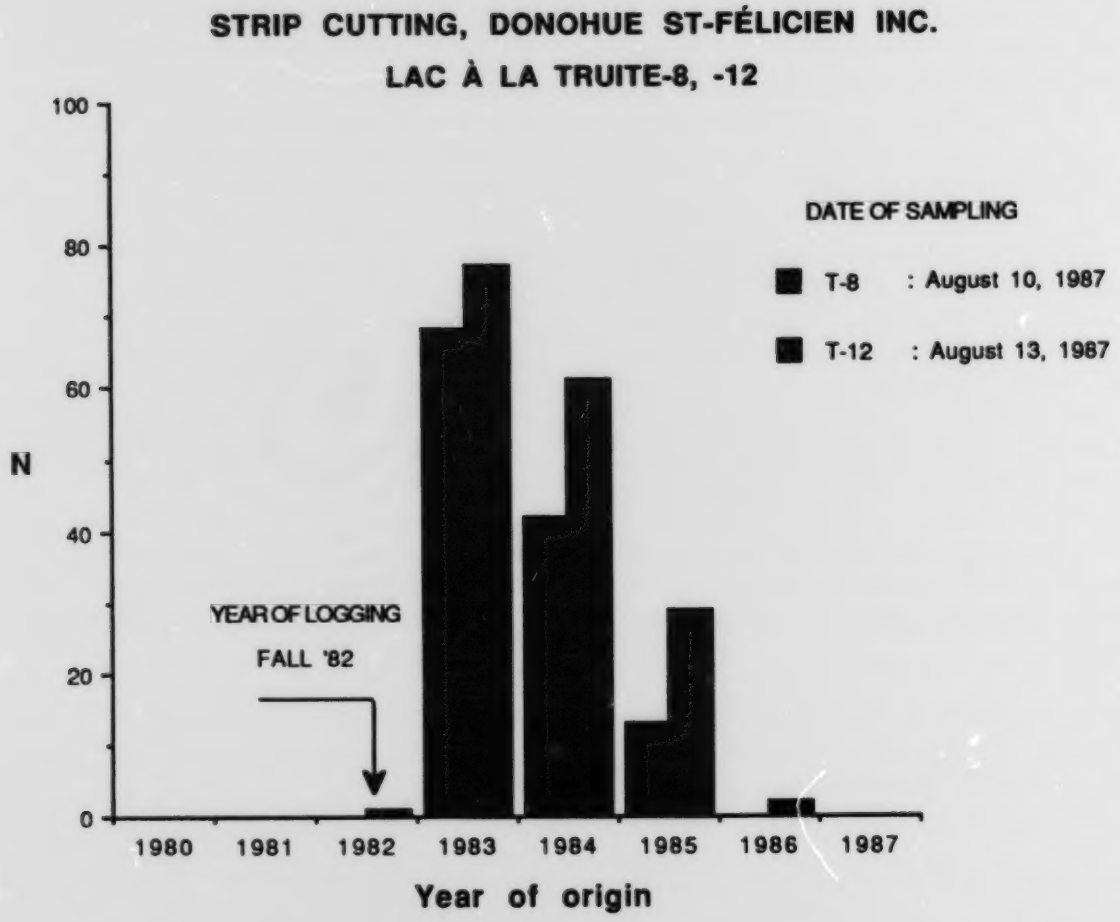

Fig. 7. Age structure of black spruce regeneration after strip cutting (seedlings from sexual origin).

reproduction of black spruce seem to be very successful. Paradoxically, we can easily grow radishes or exotic plants like wheat by direct seeding but not black spruce, a native species very well adapted to a wide ecological range. Thus, we have to roll up our sleeves and try to find the secret of Mother Nature.

ACKNOWLEDGEMENTS

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ADVANCE GROWTH ABUNDANCE AND REGENERATION PATTERNS AFTER CLEARCUTTING IN QUEBEC

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ABSTRACT

This paper presents the results of two studies on the effect of harvesting on natural regeneration. Most of the stands harvested on Quebec public lands had adequate precut stocking but experienced an important reduction in advance growth. In black spruce (*Picea mariana* (Mill.) B.S.P.) stands, regeneration stocking after 5 years was related to soil texture and harvesting system. In balsam fir (*Abies balsamea* (L.) Mill.), stand regeneration results were strongly influenced by the spruce budworm (*Choristoneura fumiferana* Clem.). Some modifications to the systems were successful in improving the preservation of advance growth but a problem still remains with feller-bunchers.

RÉSUMÉ

Cet exposé présente les résultats de deux études portant sur l'effet de l'exploitation forestière sur la régénération naturelle. La majorité des peuplements récoltés dans les forêts publiques du Québec disposaient d'une régénération préétablie abondante mais celle-ci a connu des pertes importantes lors de la récolte. Dans les peuplements d'épinette noire (*Picea mariana* (Mill.) B.S.P.), le coefficient de distribution de la régénération après cinq ans variait selon la texture du sol et le procédé de récolte. Dans les peuplements de sapin baumier (*Abies balsamea* (L.) Mill.), la régénération était fortement influencée par les dommages causés par la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* Clem.). Des modifications aux systèmes de récolte ont permis d'améliorer la protection de la régénération préétablie. Le cas des abatteuses-groupeuses demeure toutefois quelque peu problématique.

INTRODUCTION

On Quebec public forest lands, clearcutting is usually the method used to harvest mature or overmature softwood stands. This type of cutting leaves almost no seed source, so stand reproduction must rely on surviving advance growth. With the increasing mechanization that started in the '60s, advance growth often suffered heavy losses through harvesting. This led to serious concerns about the possible effects of mechanized clearcutting on natural regeneration. Two studies are presented here. The first one describes the situation that prevailed until recently, when no special precaution was taken to preserve the advance growth. In the second study, some modifications to the logging methods are made in order to improve the amount of advance growth left after harvesting.

EFFECT OF DIFFERENT HARVESTING SYSTEMS

In order to quantify the effect of different harvesting systems used on Quebec public forest lands, the first study was begun in 1982 by the Quebec Department of Energy and Resources. The study, which covers most of the province, started with 400 permanent 2-ha sample blocks, each containing 98 4-m^2 regeneration plots. Sampling intensity was in direct relation to the importance of each stand

Table 1 Proportion of stands with coniferous advance growth stocking over 75% (4-m^2 quadrats)

Stand Type	Proportion (%)
Jack pine	7
Intolerant hardwoods/softwoods	47
Black spruce	73
Spruce/fir	92
Fir	92
All cover types	73

type in the harvesting schedules. Regeneration surveys were made before and after logging. The presence or absence of regeneration was noted in each of these plots and a count was made by species on every third plot. Before logging, an inventory of stems over 9 cm dbh was made on two larger plots (0.04 ha) within each block and additional data on stand type, topography, drainage, soil texture and depth, and budworm defoliation were also gathered. The 5-year remeasurement is almost completed, so preliminary results are becoming available.

Regeneration was abundant before harvesting in the majority of the cover types studied (Table 1). Nearly three quarters of the sample blocks had more than 75% softwood stocking. Advance grwoth was abundant in black spruce and plentiful in spruce-fir and balsam fir stands. It was almost absent in jack pine stands. Advance growth composition and abundance was closely related to cover type (Ruel 1989), so results will be presented separately for black spruce and balsam fir stands. These two cover types together account for 70% of the allowable cut on public lands (MERQ 1986) and so they were the most intensively sampled.

Advance growth in black spruce stands is mostly composed of black spruce layers (Figure 1), which have recently been included in regeneration surveys. Balsam fir can also be abundant if seed trees are present in the canopy or if it is the climax species. Harvesting in these stands causes an important drop in stocking. The magnitude of losses varies with the harvesting system used, forwarders being less destructive than skidders (Table 2, Figure 2). Thus, harvesting with system 1 (see Table 2) resulted in a 19% drop, while other systems caused a 33-35% reduction in stocking. The use of feller-bunchers did not increase the destruction of advance growth compared to chainsaw-felling. With chainsaw-felling, full-tree harvesting and tree-length harvesting gave similar results immediately after harvesting. System 1 (Koehring KFF) was the only system leading to a stocking over 60% right after harvesting.

Between the first and fifth year after harvesting, stocking increased significantly so that all harvesting systems had more than 60% average stocking after 5 years. Nevertheless, stocking after 5 years was correlated to stocking right after harvesting (R2 - 0.54). Thus, stocking was higher with System 1 and softwood stems were more often in a dominant position (Figure 3). In fact, softwood stems were the tallest in more than 60% of the regeneration plots with System 1, compared with less than 50% with the other systems.

Besides being related to the harvesting system used, regeneration after 5 years is also related to soil texture. Thus, coarse textured soils that had less advance growth had less than 60% stocking 5 years later, while other soil textures had stockings over 70% (Figure 4). Both tex-

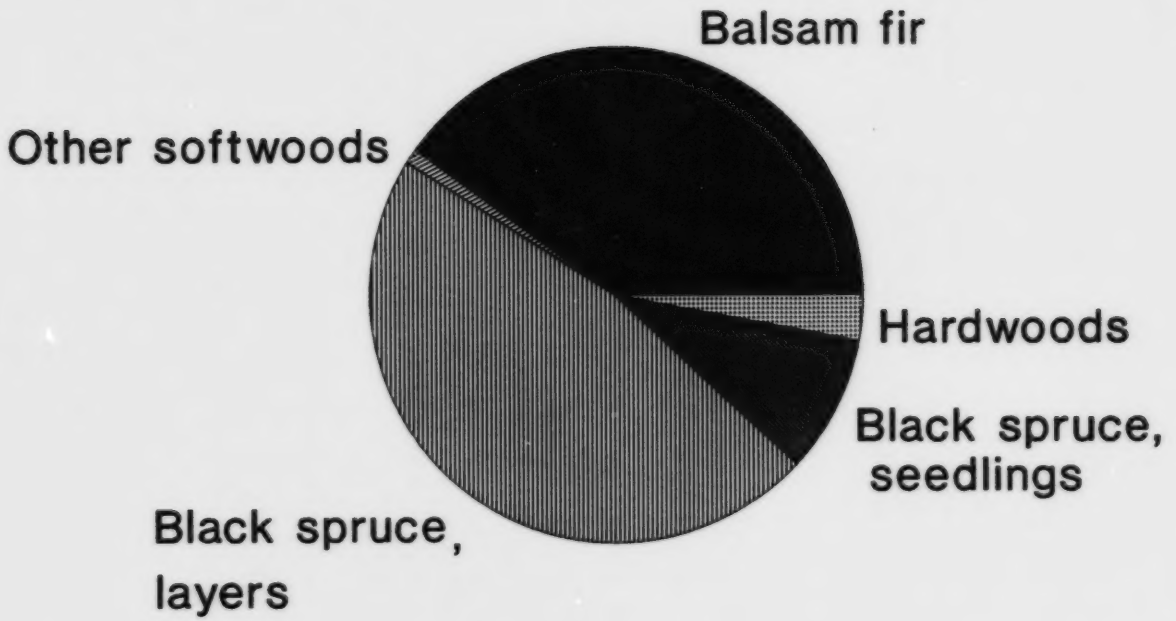

Figure 1. Advance growth composition in black spruce stands

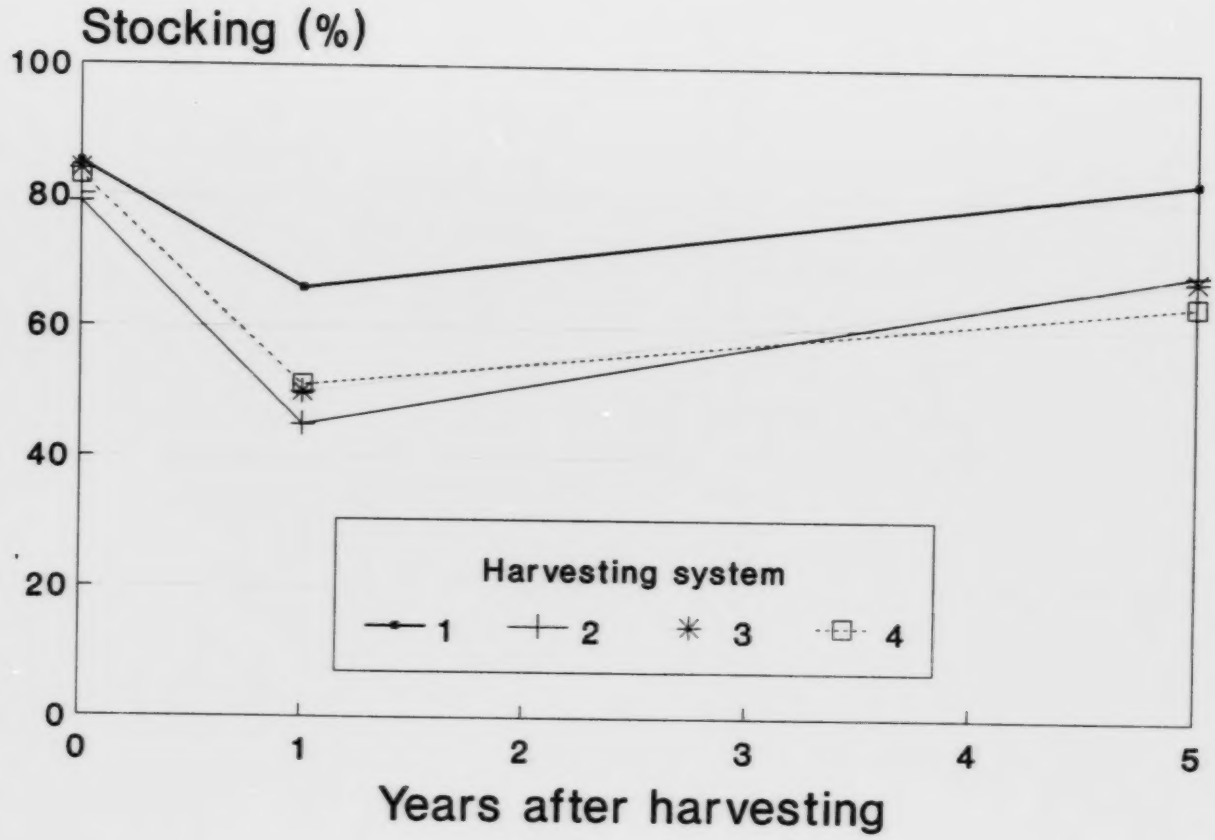

Figure 2. Effect of harvesting system on softwood stocking in black spruce stands

Table 2 Harvesting systems studied

System 1:	full tree: feller-forwarder (*Koehring KFF*)
System 2:	full-tree: feller-buncher skidder and delimber
System 3:	full-tree: chainsaw, skidder and delimber
System 4:	tree-length: chainsaw and skidder

tural classes experienced a similar decrease in stocking during harvesting and a comparable increase in the following years. Lower regeneration levels were also associated with younger stands, although sample size was quite low in that category.

These relations led to the separation of two groups of black spruce stands. The first group consists of young stands and stands on coarse textured soils; stands harvested with System 1 are excluded. In this group, cutovers with less than 40% stocking after 5 years are quite frequent (Figure 5). In the second group, which includes all other stands, stockings over 60% are the rule.

This means that emphasis should be put on stands from the first group when deciding where to sample or where to put regeneration efforts. These conclusions, drawn at a provincial scale, should nevertheless be validated on a regional basis.

In balsam fir stands, preharvest stocking was above 90% and regeneration was largely dominated by balsam fir. The effect of the two harvesting systems commonly used in those stands (Systems 3 and 4) was rather similar (Figure 6). Even though an important decrease in advance growth occurred, stocking was still around 60% right after cutting. With the small increase in stocking taking place between the first and fifth year, regeneration could be considered, in general, satisfactory.

In addition to logging, infestation by the spruce budworm plays an important role in regeneration of balsam fir stands (Baskerville 1975; MacLean 1984). In stands affected most recently (beginning in 1976), softwood stocking before harvesting does not vary much between defoliation classes (Figure 7). Nevertheless, the presence of stems taller than 1 m decreases with increasing defoliation. Hardwood stocking, mostly paper birch (*Betula papyrifera* Marsh.), was also higher in severely defoliated stands.

In the stands where the infestation lasted longer (beginning in 1970), stems over 2 m were almost absent and those below 50 cm provided most of the stocking (Figure 8). Hardwood stocking was quite similar to more recent infestations, but taller stems were becoming more abundant. Thus, a spruce budworm infestation changes the structure and composition of advance growth. It does so by opening up the overstory, creating canopy gaps giving way to an invasion by intolerant species and also by destroying the taller advance growth (Mott 1974; Fowle 1983). This could lead to increased competition problems both before and after salvaging. In fact, data collected 5 years after harvesting tend to corroborate this hypothesis (Figure 9). Looking at two contrasting situations, stands slightly defoliated for a short period and those heavily defoliated for a long period, it can be seen that coniferous stems assume a dominant position in 42% of the regeneration plots in the first case, while in the second case, only 18% of the plots show a dominant softwood regeneration. Moreover, 88% of the stands least affected by the budworm had softwood stockings of over 60% after 5 years compared

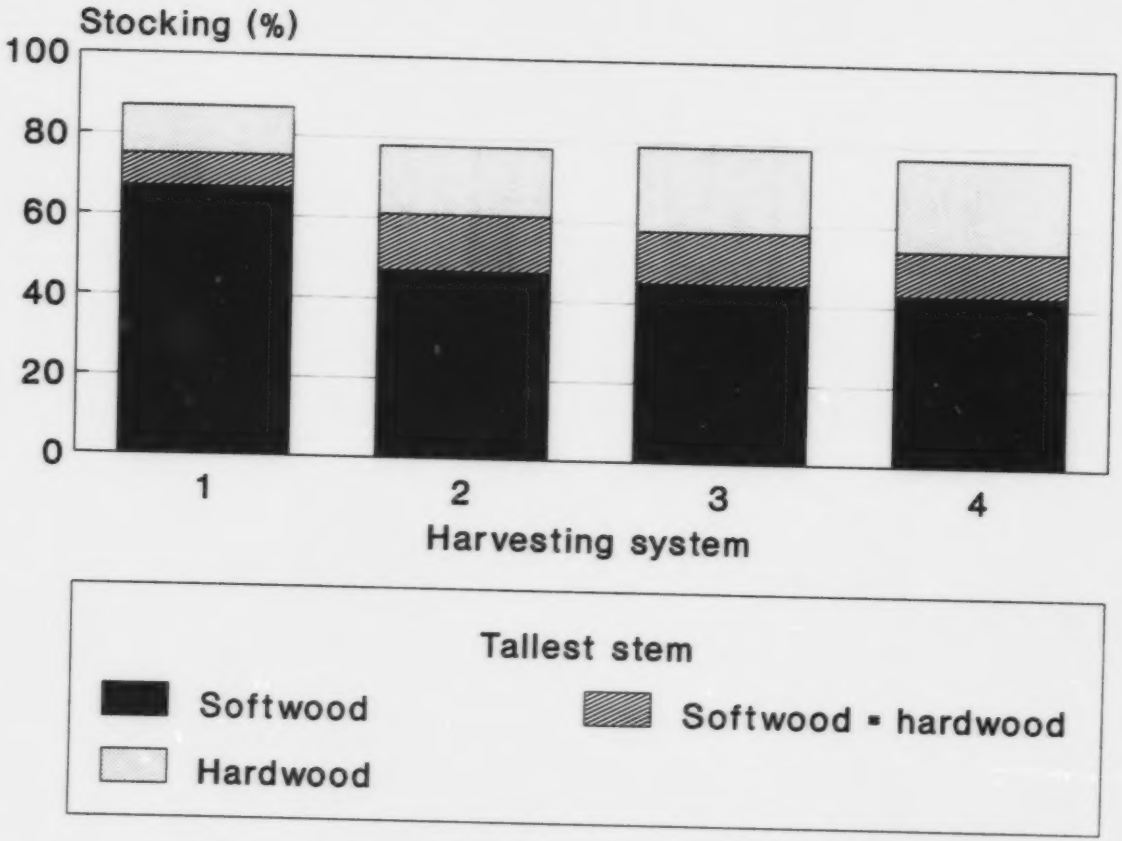

Figure 3. Stocking based on the tallest stem per quadrat in black spruce stands, five years after harvesting

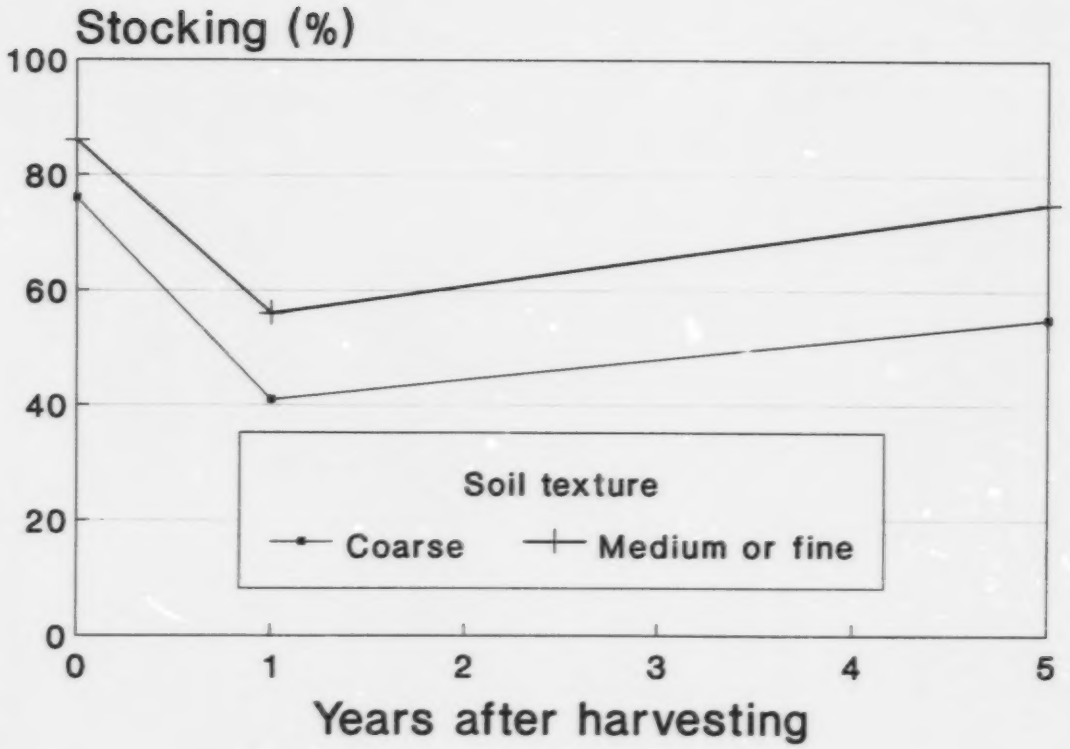

Figure 4. Influence of soil texture on softwood stocking evolution in black spruce stands

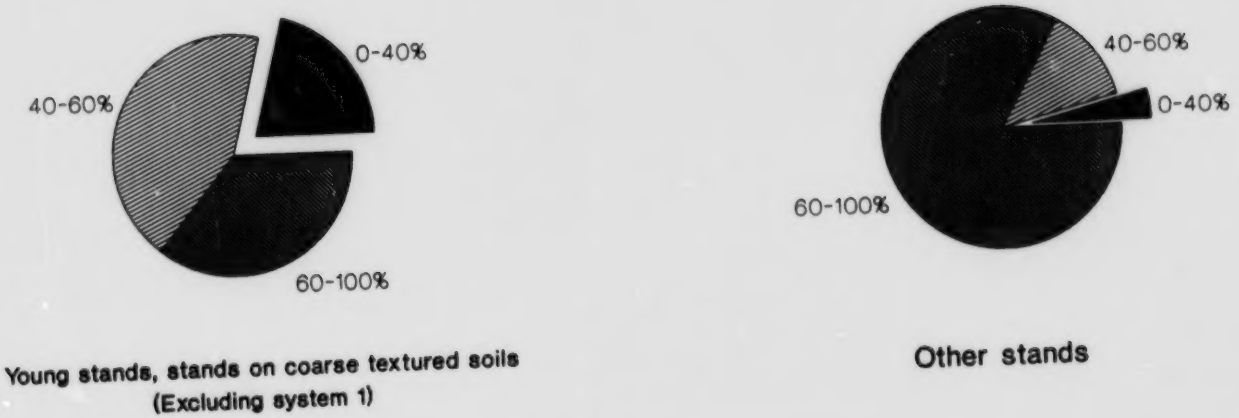

Figure 5. Softwood stocking by group of black spruce stands five years after harvesting

Table 3 Undisturbed width between skid trails

Type of feller-buncher	Width (m)
B.J. 20	7.1
Caterpillar 215	7.5
Timbco	8.0
Tanguay AC-200	10.4
Denis feller-delimber (prototype)	20.0

to 61% in the worst situation. So, even though regeneration levels are generally high, regeneration failures and competition problems may be quite different and the need for release treatments will depend on spruce budworm defoliation.

PRESERVING THE ADVANCE GROWTH

Since advance growth was abundant but generally suffered heavy losses, a second study, aiming to find some ways to increase its survival, was started. The following modifications were implemented (Canuel 1987, 1989):

- fell the trees to minimize sweeping during winching (20-30 angle with skid trail);
- maximize the distance between skid trails;
- restrict all machinery to these trails;
- avoid unnecessary cleaning around the trees to be harvested;
- skidders must turn around in non-regenerated clearings, as far apart as possible.

This study consists of pairs of blocks, approximately 2 ha in size. The first block was cut without any special care for the advance growth by logging crews with no prior experience of the modifications to be implemented. Before cutting the second block, they were instructed about the study objectives and the method to be used. Sampling methods were similar to the first study.

With these modifications, 60% stocking after harvesting was obtained in all trials with the Koehring KFF and Koehring Shortwood harvester (Figure 10). Preharvest stockings had to be more than 90% in order to obtain an equivalent stocking in control blocks. With chainsaw felling, 60% stocking was obtained with preharvest stocking of 77% and the modifications already mentioned, or with 92% without modifications (Figure 11). In both systems, the average loss of stocking could be limited to about 15%.

More recent trials have been directed to the use of feller-bunchers. With this type of machinery, a precut stocking of about 94% was required to maintain a 60% stocking after harvesting on the controls but, with the modifications, 84% was enough. This is fairly close to a 25% drop reported in regular logging operations at Abitibi-Price and Stone-Consolidated (Houde 1988).

Thus, the destruction of advance growth remains higher than with the other systems. This comes from the fact that the limited reach of the available feller-bunchers requires a closer spacing of the skid trails. Since this reach varies with the type of machinery used, results will also differ (Houde 1988) (Table 3). In general, the undisturbed width between skid trails was less than 10 m. Nevertheless, a prototype made by fitting a felling head to a delimber gave promising results, increasing

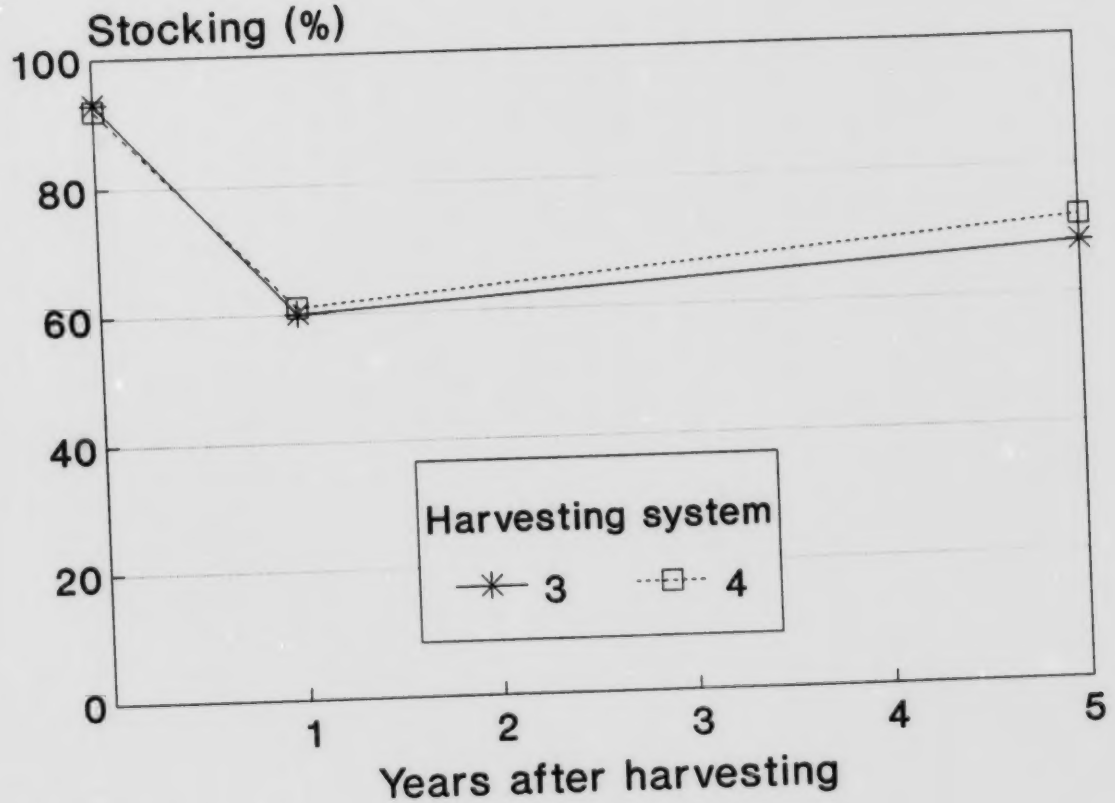

Figure 6. Effect of harvesting system on softwood stocking in balsam fir stands

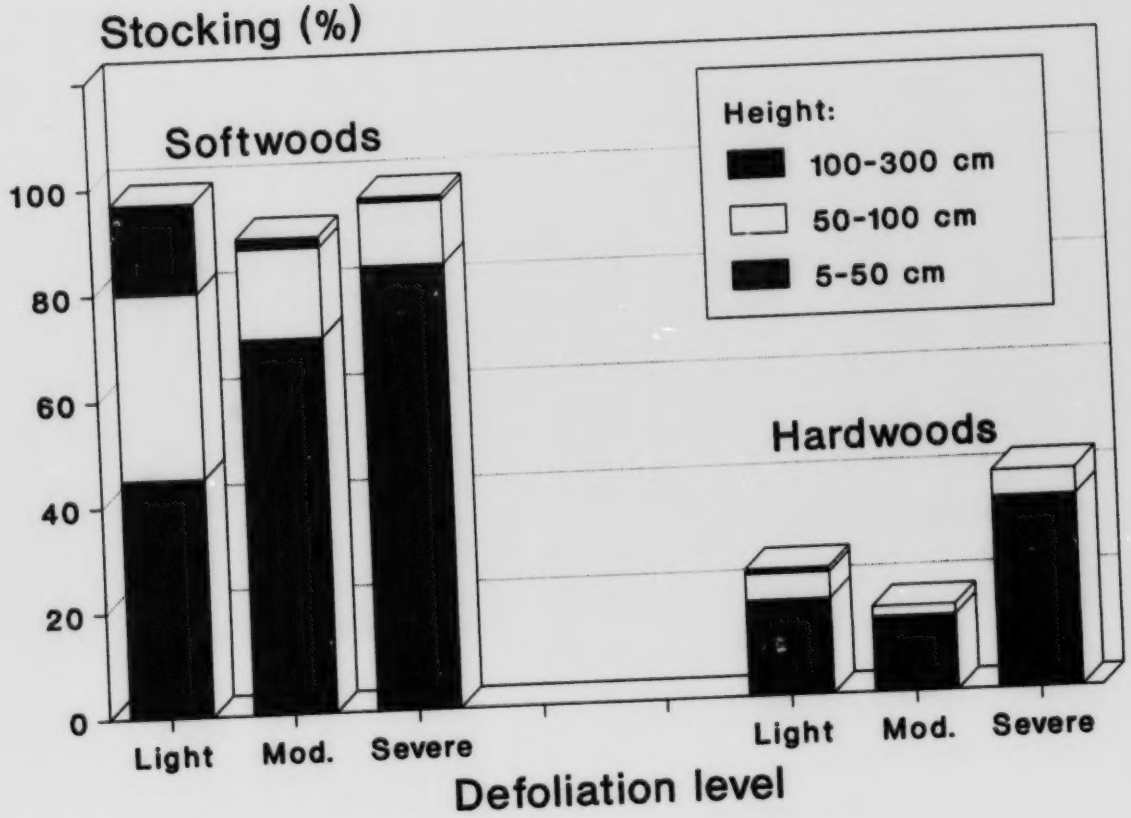

Figure 7. Size class distribution of advance growth in balsam fir stands (shorter infestation period)

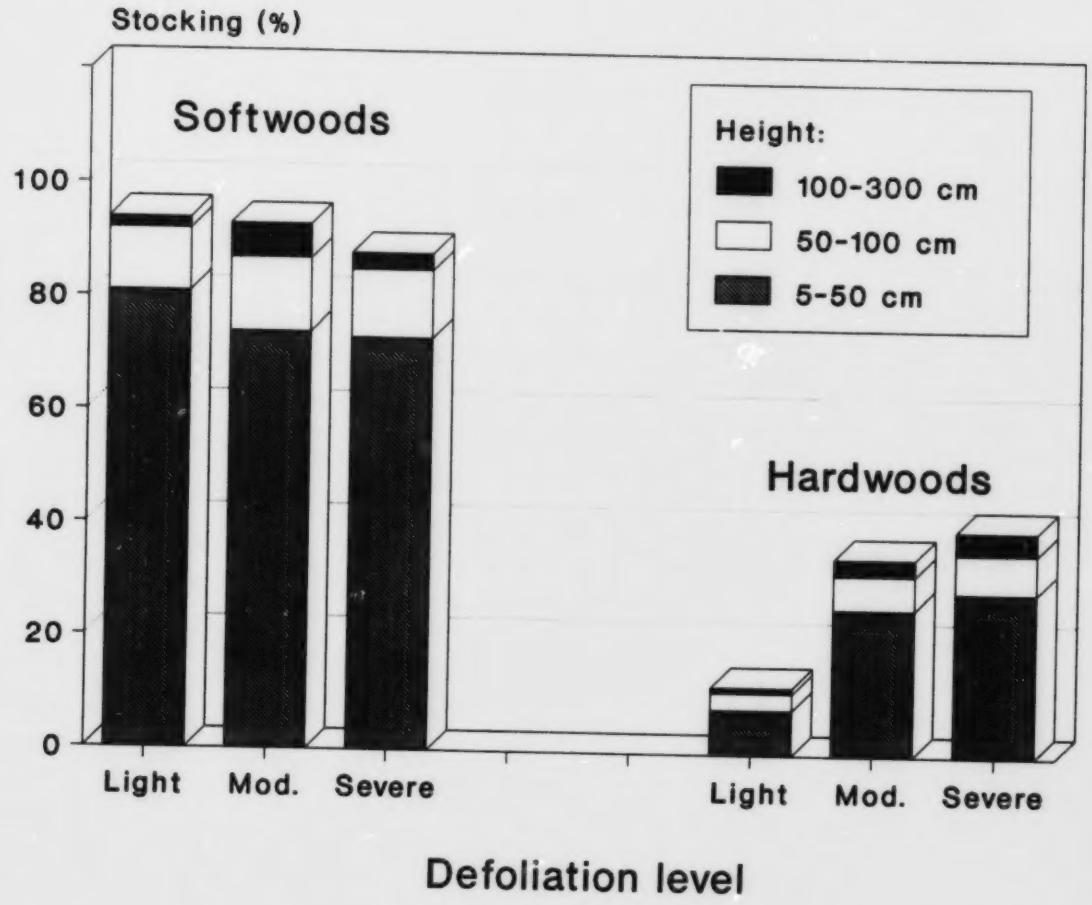

Figure 8. Size class distribution of advance growth in balsam fir stands (longer infestation period)

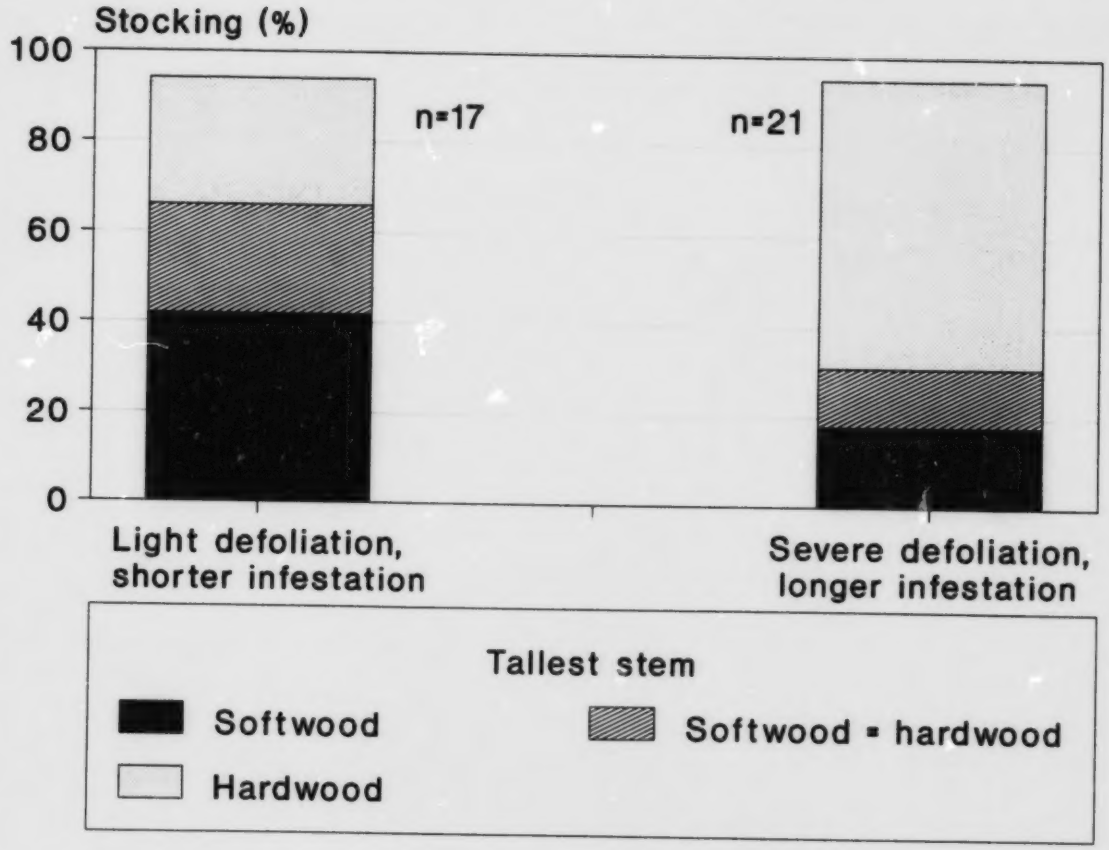

Figure 9. Effect of the spruce budworm in balsam fir stands, based on the tallest stem per quadrat

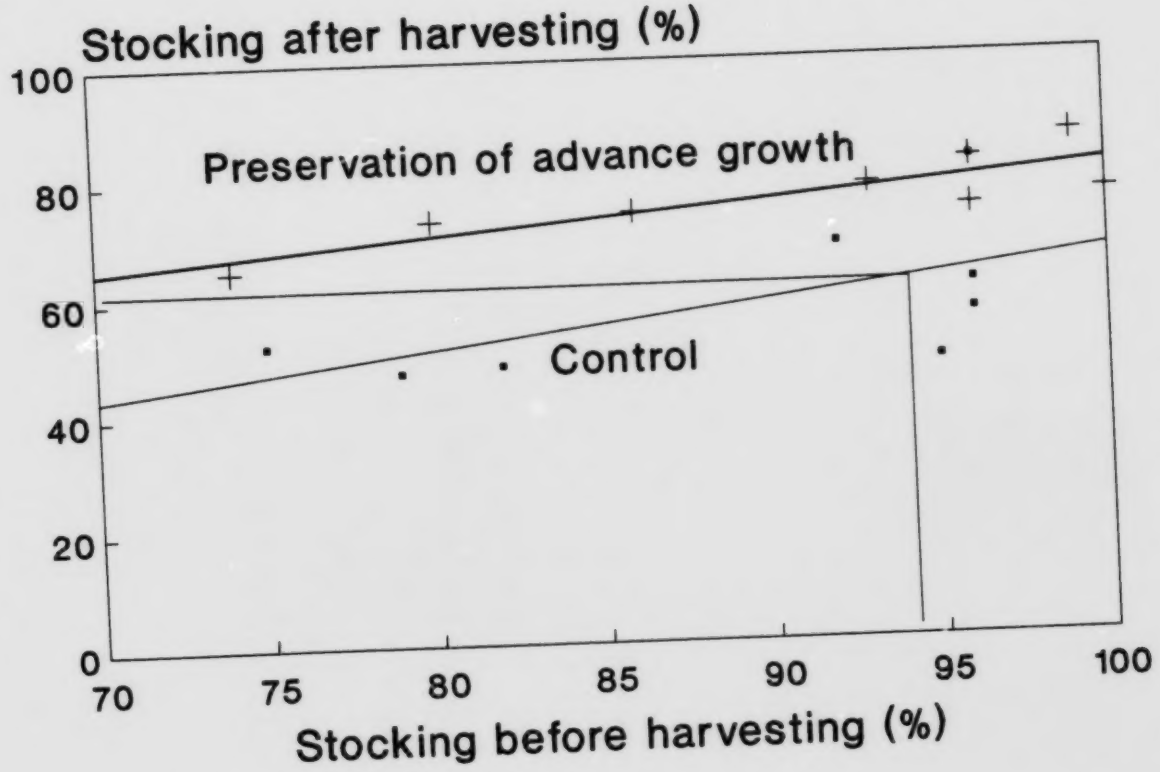

Figure 10. Preservation of advance growth in balsam fir stands: *Koehring KFF* and *Shortwood Harvester*

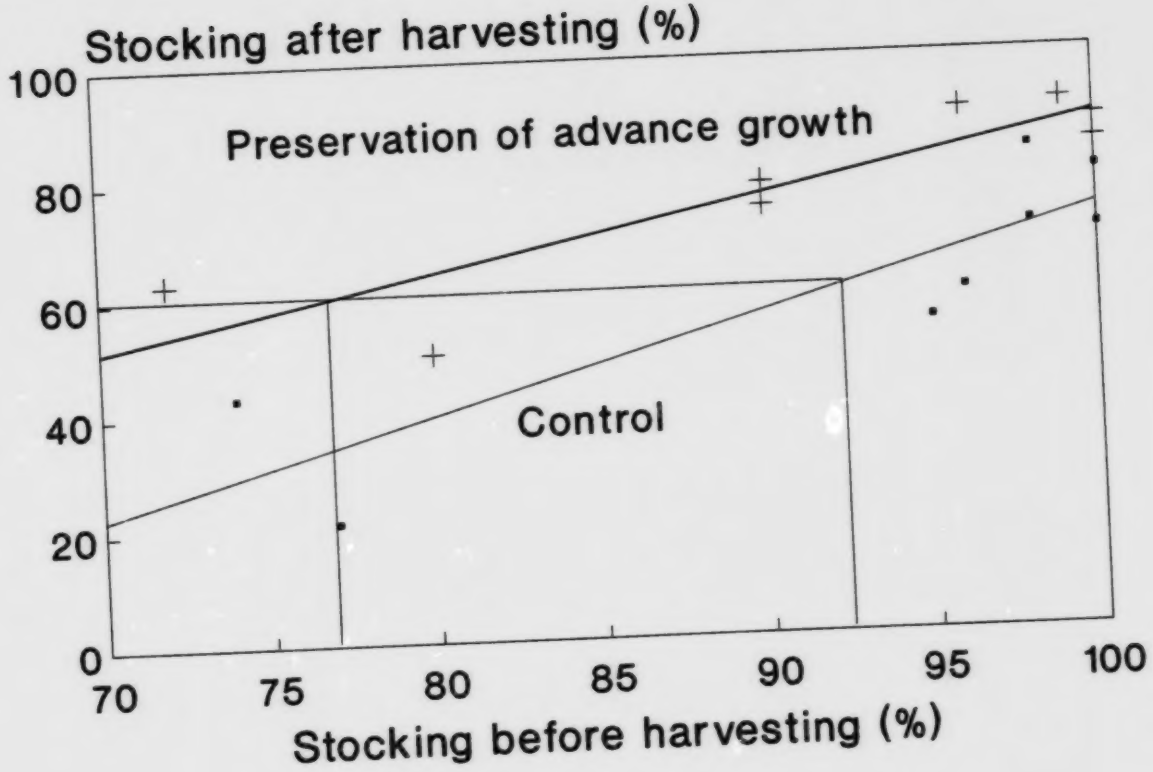

Figure 11. Preservation of advance growth in balsam fir stands: chainsaw felling

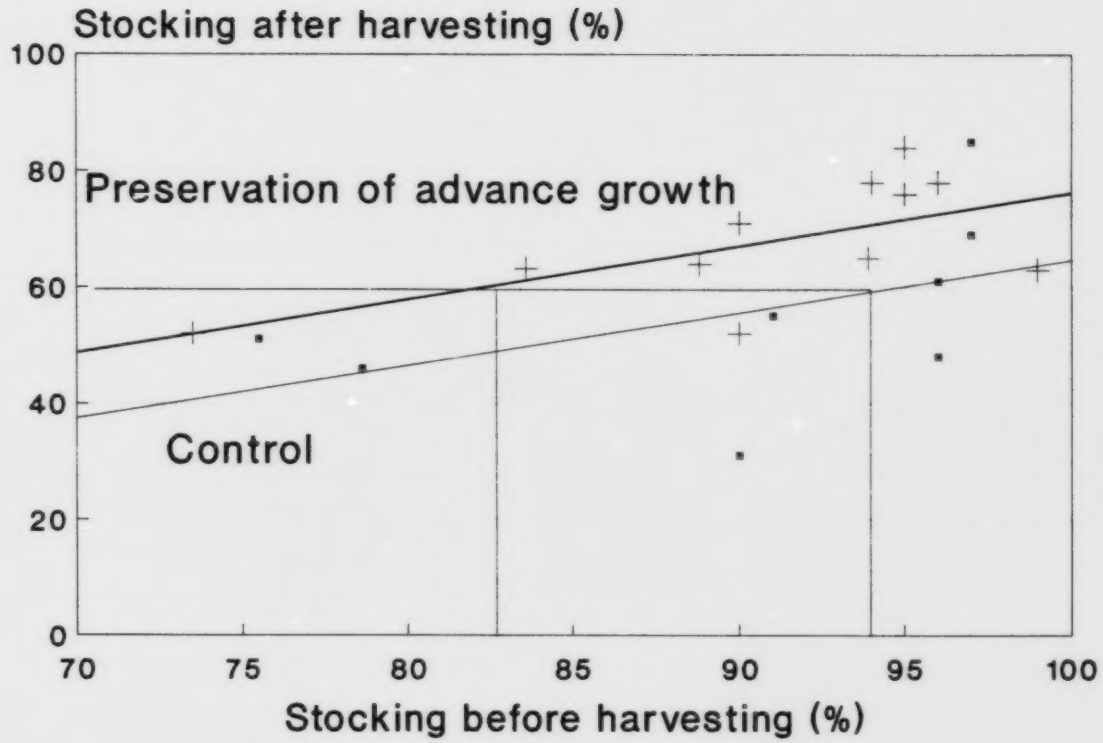

Figure 12. Preservation of advance growth with feller-bunchers

this distance to 20 m. Thus, introduction of new machinery could do a lot to improve the preservation of advance growth with mechanical felling.

CONCLUSION

In most of the stands being harvested on Quebec public lands, successful natural regeneration can be obtained by preserving advance growth. This can be done by using a less destructive harvesting system, by harvesting in winter or by changing the working methods for a particular system. Given the obligation of regenerating their clearcuts and the low cost of this approach, most industries are getting into the preservation of advance growth. In fact, it is estimated that the preservation of advance growth was applied to more than 136 000 ha in 1989-1990.

Regeneration problems will still exist, either because advance growth is inadequate or because ground conditions are too rough to efficiently apply the method. To better predict the results that can be expected, local advance growth predictions and experience gained by the industry will be very useful.

ACKNOWLEDGEMENTS

The author wishes to thank his colleagues who started and ensured the follow-up of both studies, particularly G. Rhéaume, B. Canuel, C. Deschênes, and A. Proulx. Collaboration of M. Huot was also very helpful in analyzing the results of balsam fir stands damaged by the spruce budworm.

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GROWTH PERFORMANCE OF MATURE SECOND-GROWTH BLACK SPRUCE IN THE SAGUENAY-LAC ST-JEAN REGION, QUEBEC: PRELIMINARY RESULTS

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INTRODUCTION

Forest regeneration after harvest is obviously the major concern of today's forester. Among the existing techniques, protection of advanced growth during logging seems to be a potential solution to the regeneration problems of black spruce stands. It is a relatively low-cost technique that provides sufficient stocking when advanced growth is abundant. However, the second-growth black spruce stands differ markedly from the stands from which they originate. Considering that black-spruce advanced growth is mainly composed of layers (Doucet 1988a) and that post-harvest seedling establishment is scarce even if a sufficient seed-source is left (Morin and Gagnon 1988), second-growth black spruce stands are made up of layers, unlike virgin black spruce stands, which are mainly composed of seed-origin individuals established after a natural forest fire (Gagnon *et al.* 1991).

The proliferation of second-growth black spruce stands raises a new question: will these stands perform as well as the natural, seed-origin black spruce stands? We have little knowledge of the growth and yield of black spruce following harvest. Contrary to the belief of some foresters, layers may grow equal to, or higher than, trees of seed origin (Stanek 1968). Similar results were obtained by comparing recently released layers to planted or natural black spruce seedlings after logging (Vincent 1964, Doucet and Boily 1986).

Many authors conclude that the performance of second-growth stands is comparable to the yield tables data currently available (Morin and Gagnon 1990, Paquin 1990, Doucet 1988b, Horton and Groot 1987) . In all probability, these tables were obtained by measuring natural, post-fire stands. Unfortunately, it is a rather imprecise comparison, considering the high variance of the yield tables data which are not well-suited to evaluate the productivity of a single stand.

The objective of our study is to compare the growth of mature black spruce layers from second-growth stands to fire-origin individuals in similar site and competition conditions. It is part of a research project on the performance of second-growth black spruce stands funded by NSERC and the Abitibi-Price Company.

This paper presents the very first results of this study.

MATERIAL AND METHODS

Field work

Six natural and six second-growth black spruce stands were selected on dry, mesic, and wet sites in the Réserve faunique des Laurentides, located in the oldest cutover areas in the Saguenay-Lac St-Jean region. The Abiti-Price company has kept logging records since the 1890s, which coincides with the beginning of major black spruce exploitation, primarily for lumber and later for pulpwood.

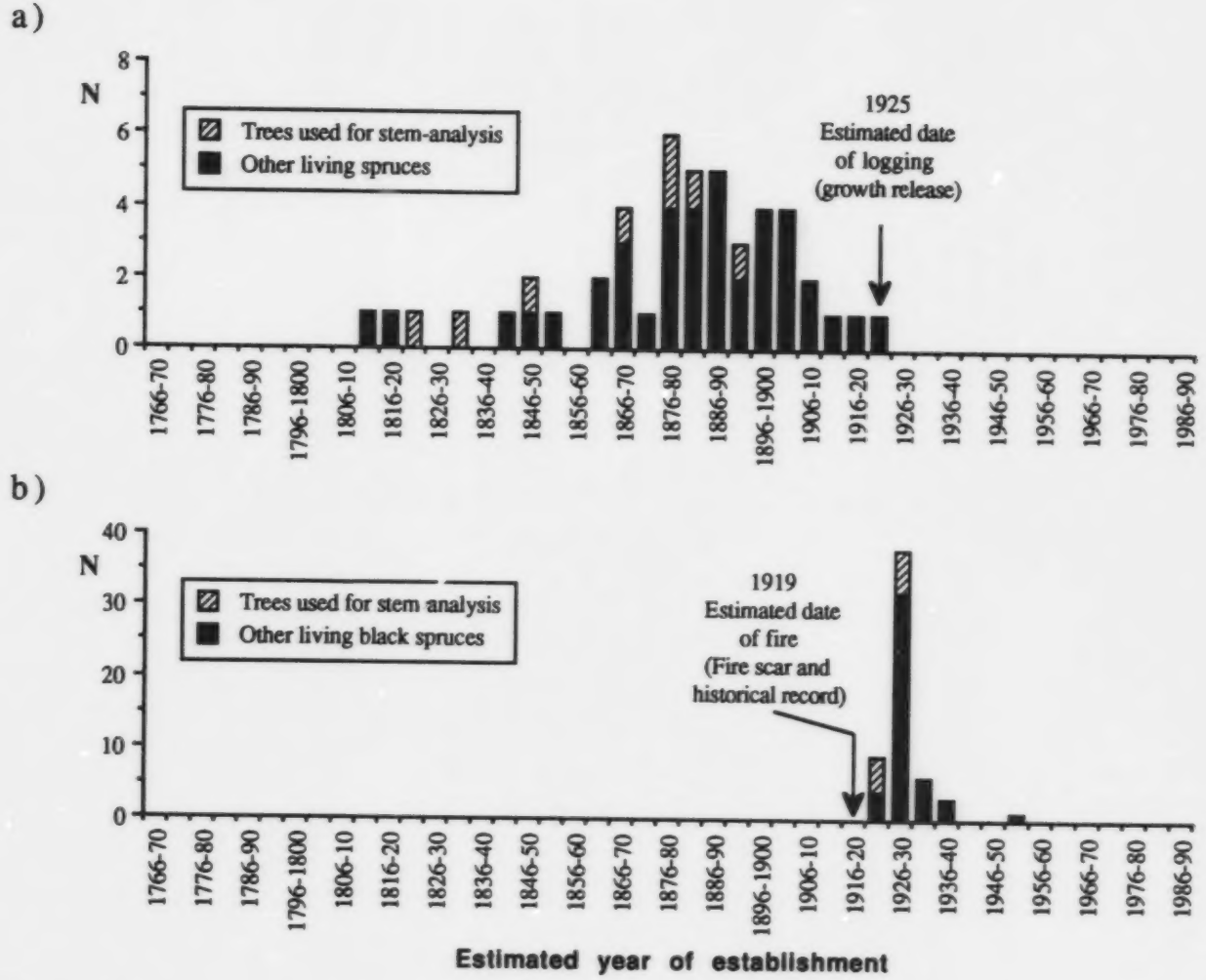

Figure I: **Age structure of sampled (a) second-growth and (b) fire-origin black spruce stands on mesic sites, high point density (including all living spruces in 1989 with DBH ≥ 2,5 cm)**

Second-growth stands were identified in the field by remaining stumps and evident growth acceleration on cross-sections at the base of mature spruces. Typically, second-growth trees show an early suppressed period of variable length, followed by a release of radial growth caused by the harvest of the merchant stems (Morin and Gagnon 1990). Fire-origin dominant black spruce trees show a different growth pattern, without early suppression. The origin date of such stands can be confirmed by trembling aspen roots suckers (Mercier *et al.* 1989), by fire-scars (Heinselman 1973) and historical records. Stand origin can also be confirmed by age structure, established by a ring-count of cross-sections of all trees (2-cm dbh): even-age structure can be associated with fire-origin stands (Heinselman 1981), while second-growth stands typically show a positively-skewed, uneven age structure (Légère and Payette 1981; Morin and Gagnon 1990).

First, the 12 sampled stands were chosen following a stratified random sampling, in which drainage, mean point density and origin were the stratification variables. In each stand, a 200-m^2 plot was established, in which every tree was mapped and felled for stem analysis. Stems were cross-cut at ground level, 30 cm, 60 cm, 1 m, 1.3 m, 2 m, and every following meter.

Second, merchant trees (9-cm dbh) were stratified by Spurr's point density, which estimates the degree of competition on a tree in a stand (Spurr 1962). This method is based on the Bitterlich angle count, therefore point density is expressed in square meters per hectare. Two classes of point density were then delimited, a low density class which ranges from 20 to 34 m^2/ha, and a high density class which ranges from 40 to 54 m^2/ha.

One hundred and twenty trees were randomly selected in the 12 stratification groups (10 trees x 2 origins (fire or second-growth) x 3 drainage types (dry, mesic or wet) x 2 density classes (high or low density).

Laboratory work

Prior to measurement, all stem cross-sections were dried and finely sanded. Growth-ring width measurement and stem analysis were performed respectively with the MacDENDRO and WINGTIGES systems, both elaborated by the National Optic Institute and the Université du Québec à Chicoutimi. These systems analyze images of cross-sections obtained by an optical scanner along two or four radii and measure ring-width. It is then easy to get the annual variation of diameter for each cross-section. Volume between two consecutive cross-sections is estimated by means of cone frustums, while the tip approaches a cone in form. Total volume is obtained by the summation of all the sections' volume. Height growth was estimated with Lenhart's formula which evaluates the position of the apex at each year using the number of rings counted on a cross-section taken at known height (Lenhart 1972). The general concepts of stem analysis are set forth in Husch *et al.* (1982).

ANOVA and current mean comparison tests were used in growth curve comparisons, using a probability level of 95%.

RESULTS

This paper will focus on data from second-growth and fire-origin black spruces growing on mesic sites and which are associated with a high point density. This represents only a third of all the study's data; the treatment of the remaining data is in progress.

Stand description

Figure 1 illustrates the age structure of the stands where the trees were sampled. As shown, all trees of the second-growth stand were established prior to harvest, forming an uneven-age structure, although the distribu-

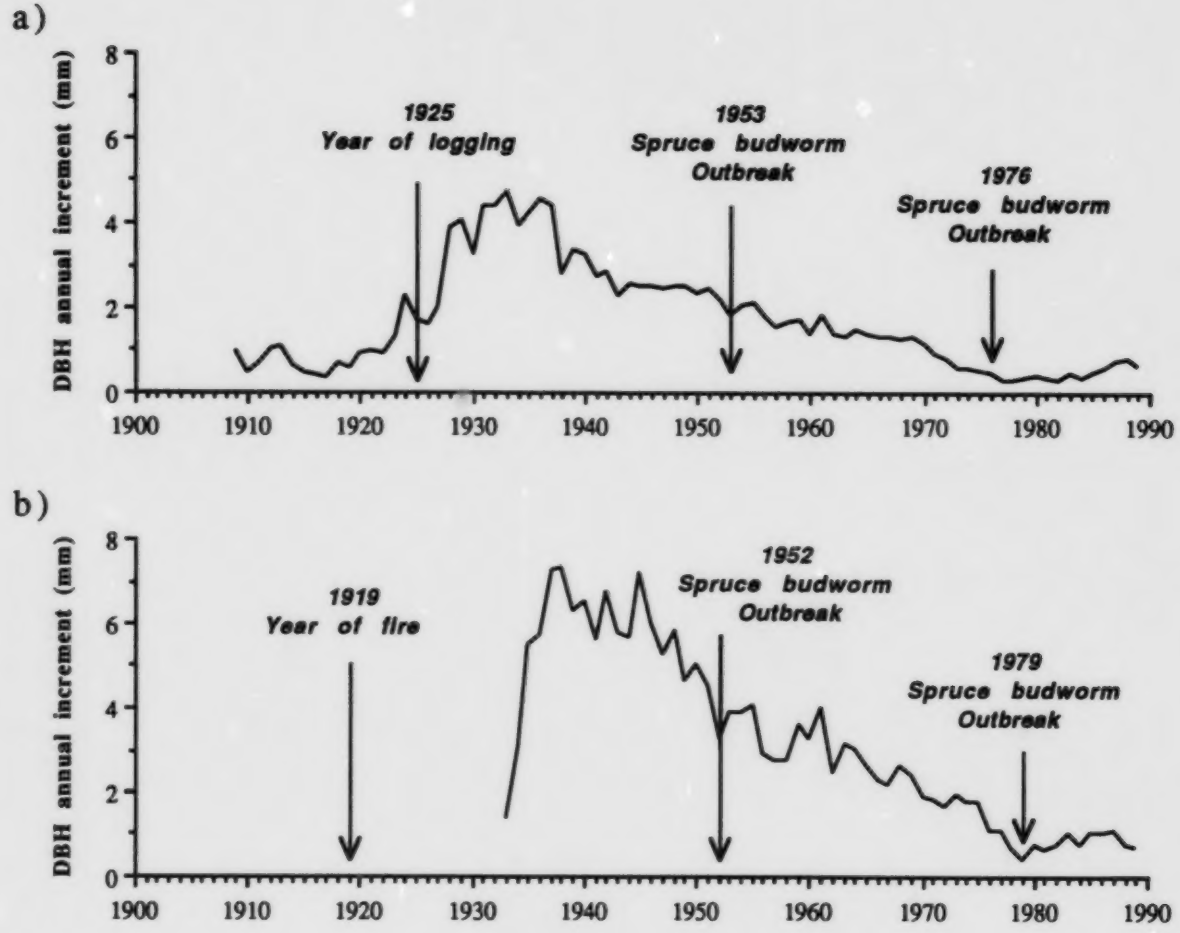

Figure II: **Breast height diameter annual increment of (a) a second-growth and (b) a fire-origin black spruce tree on mesic sites, high point density (respectively sampled trees nº MMH-69 AND nºSMH-10).**

Table 1 Sampled plots (200 m^2) mensurational characteristics in 1989[a].

	Origin	Mean dbh cm	Density Stems	Basal area m^2	Merchant volume[b] m^3
Second-growth	1925	11.8	53	1.04	5.01
Fire-origin	1919	10.7	57	.93	3.98

[a] Including all stems with dbh ≥ 2.5 cm.

[b] Estimated with local volume tables (Anonymous 1989), assuming that volume-per-dbh is comparable in second-growth and fire origin trees

tion is not positively skewed. Such a pattern is not an exception, according to the results of Horton and Groot (1988).

The fire-origin sampled stand was established after a fire which occurred in 1919, dated by a fire scar and mapped historical records. Installation period is much shorter when compared to the previous stand, most trees being established during 5-7 years, preceded by a period of 5 years with no regeneration. However, one should be aware that this is probably not the real pattern of establishment: effectively, the work of St-Pierre (Gagnon *et al.* 1991), confirmed that establishment of seedlings begins the first year following a fire and continues for about three years.

Both sampled plots show rather high densities and yields (Table 1), with merchant volumes of 251 and 199 m^3/ha, which is far beyond the data found in empirical yield tables (Boudoux 1978) and in most second-growth studies (Morin and Gagnon 1990; Doucet 1988b; Horton and Groot 1987). However, those volumes concern the 200-m^2 sampled plots chosen for their high densities and not the entire population.

Breast-height diameter growth pattern

At the time of harvest, the sampled second-growth black spruce trees had an average inside bark dbh of 4.43 cm (STDEV=3.10), based on measurements of dried cross-sections. Comparison of breast-height diameter increments reveals that second-growth and fire-origin black spruce have different growth patterns (Figure 2). The two dbh increment curves illustrated here are from a second-growth black spruce which had a dbh of 1.5 cm and a height of 2.6 m at the time of logging and from a seed-origin black spruce probably established one to three years following the 1919 fire. After a period of evident suppression, the second-growth dbh curve shows an important growth acceleration after harvest, which then progressively decreases. The fire-origin spruce shows a similar reduction of annual increment, without of course the initial suppression.

On both curves, we observe a reduction in growth in 1952-53 and during a period which varies from the late 1970s to the early 1980s, evidence of major spruce budworm outbreaks in the studied region (Blais 1965, 1983; Morin and Laprise 1990). Ring-width reduction is more evident for fire-origin spruces, which suggests that the sampled fire-origin stand has been more severely predated by spruce budworm. As will be shown later, the spruce budworm outbreak had a significant impact on black spruce volume growth, although it seems to vary among sites and specific trees.

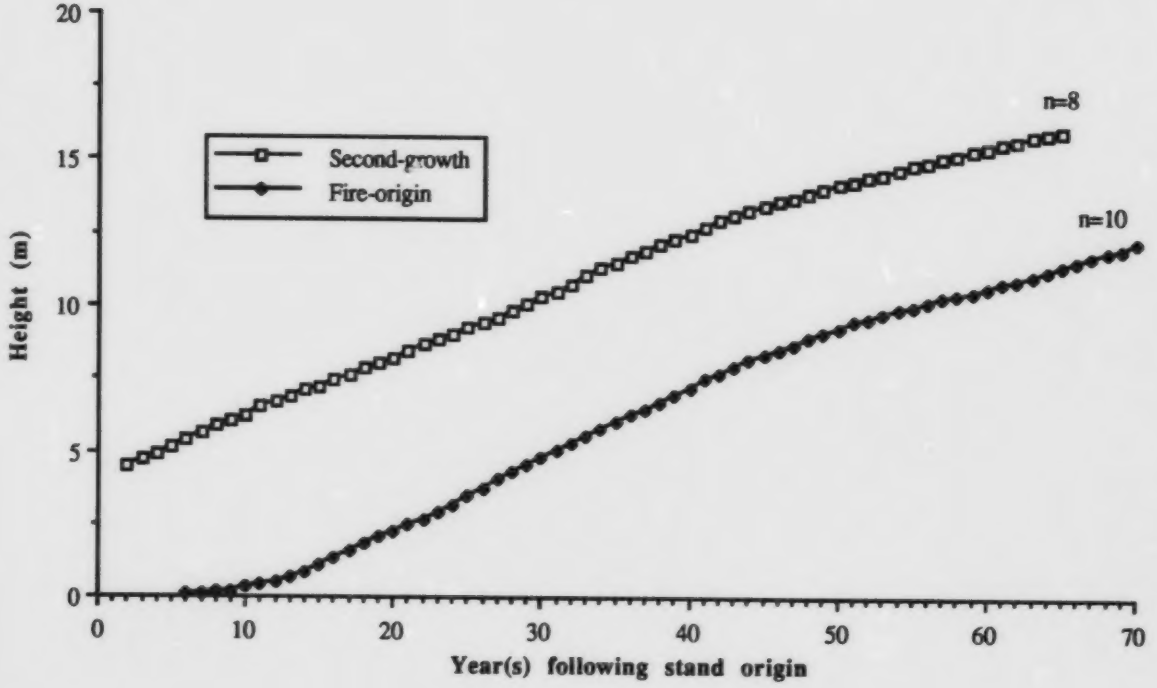

Figure III: **Average height growth of fire-origin and second-growth black spruce trees on mesic sites, high point density**

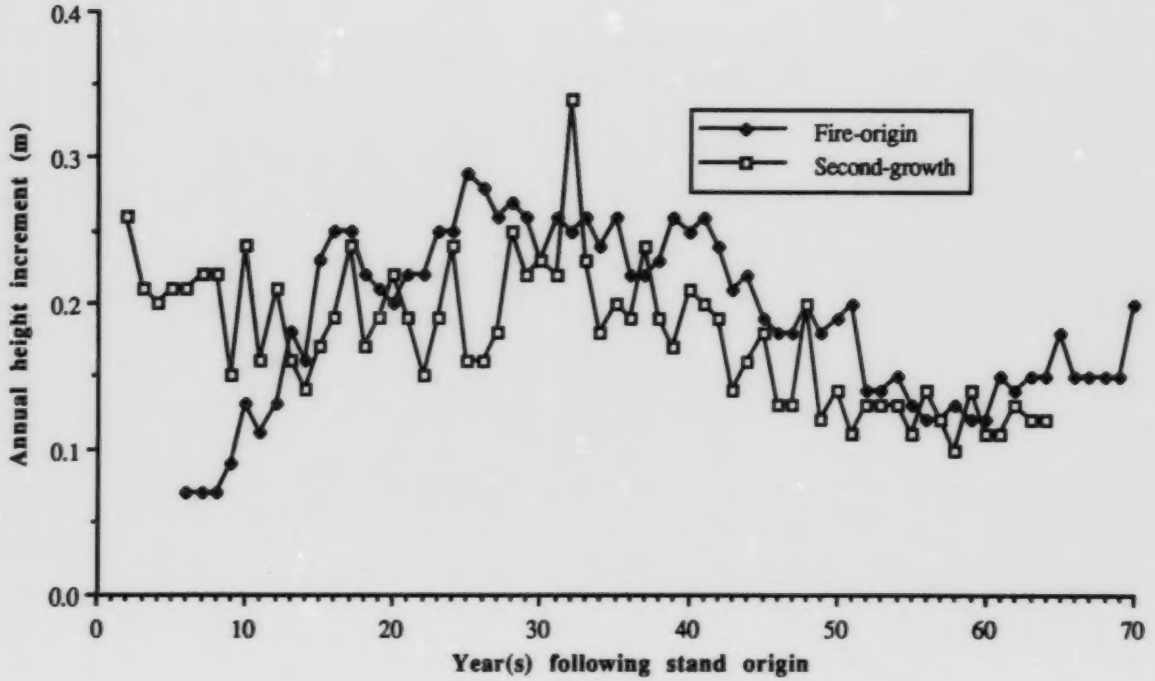

Figure IV: **Average annual height increment of second-growth and fire-origin black spruce trees on mesic sites, high point density**

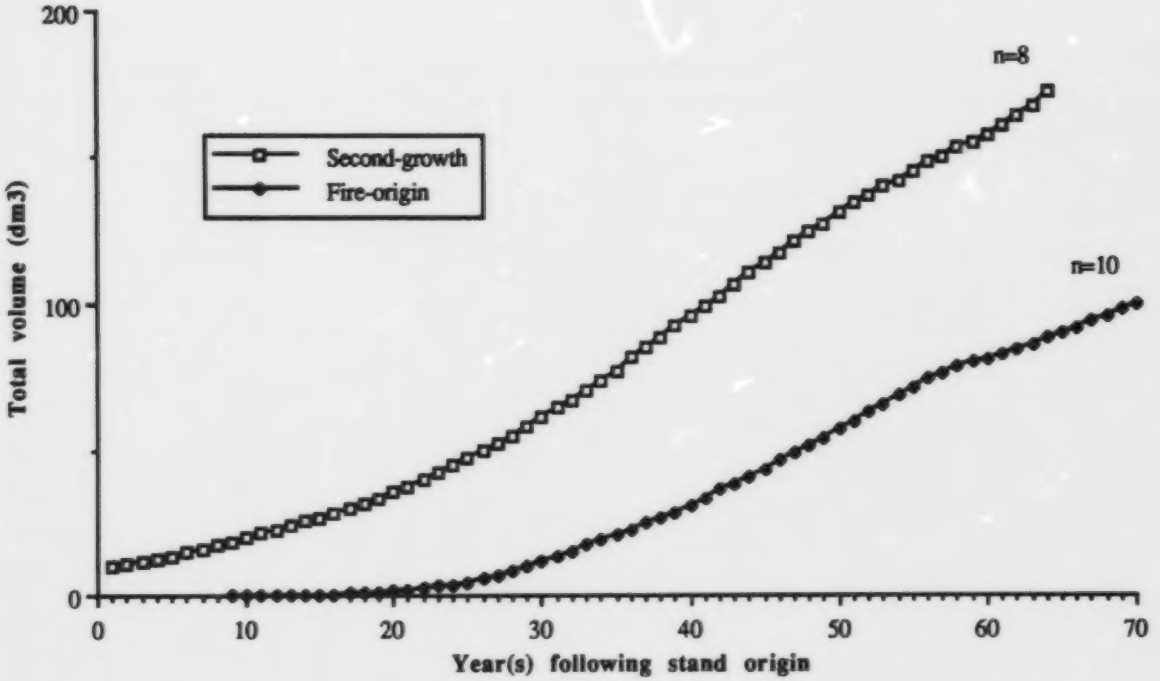

Figure V: **Average total tree volume growth of fire-origin and second-growth black spruce on mesic sites, high point density.**

Comparison of height growth

Average height growth curves of seed-origin (n = 10) and second-growth black spruce (n = 8) were compared by fitting the date of origin of each stand on the X axis (Figure 3). In 1926, black spruce layers had a mean height of 4.45 meters (STDEV = 2.42), which mostly explains their height advantage over the years. Increment superiority of layers was effectively limited to a period of 10 years after the stand establishment (Figure 4). Afterwards, seed-origin spruce showed an equal or significantly superior height increment. During this period, height increment in a first stage remained relatively constant, and then progressively decreased between 1959 and 1979. Spruce budworm predation may have contributed to this reduction, since height increment seemed to be more important after the last major outbreak.

Comparison of total volume growth

Like height growth, average total volume growth for the sampled trees was compared by fitting both stands date of origin (Figure 5). For all the years following stand origin, second-growth spruces (n = 8) attained significantly higher volumes than fire-origin trees (n = 10). This can be explained by the size of advanced growth at the time of harvest, which gives it an important advantage compared to seed-origin trees.

Total volume increment is significantly higher for second-growth spruces, up until the thirty-second year, at which point there are no significant differences between seed-origin and second-growth trees, except for small periods where second-growth volume increment is higher. We are not able to explain this pattern at the moment except for a short period where the differences can be attributed to more important damage caused by the spruce budworm on the sampled fire-origin stand. However, we cannot prove an evident relation between stand origin and its vulnerability to spruce budworm for the moment.

Longitudinal variation in stem diameter increment also seems to differ between second-growth and fire-origin black spruce (Figure 6). Stem profiles reveal that mature layers allow more increment in the upper part of the stem, which results in a lower taper than in seed-origin trees. Consequently, in our case, a mature second-growth spruce gave significantly more volume than a seed-origin spruce of equal dbh, the volume-per-dbh ratio being respectively equal to 10.51 and 6.99 dm^3/cm. This result could cause some bias in volume table utilization, but it is too early to generalize.

Comparing tree volume growth curves from other sampled plots indicates the high variability of black spruce growth (Figure 7). It is unfortunately too early to identify precisely all the causes of such variations. It seems however that point density is a reasonable estimator of intraspecific competition, as shown by the higher volume growth of low-density seed-origin spruce compared to high-density ones (both growing on mesic sites).

CONCLUSION

These preliminary results indicate that second-growth black spruce can perform as well as, or better than fire-origin trees, showing a superior height, dbh, and volume, a comparable number of years after stand origin. They also suggest that the layer superiority depends greatly on their size at the time of logging. A relation between height growth and height at the time of logging has been already observed by Horton and Groot (1987) and Paquin (1990). In most cases, the trend is curvilinear, which suggests greater growth response after logging from smaller stems. Our data do not seem to contradict this relation, although it was necessary to add data from another group of layers to ensure a significant number of samples (Figure 8). This

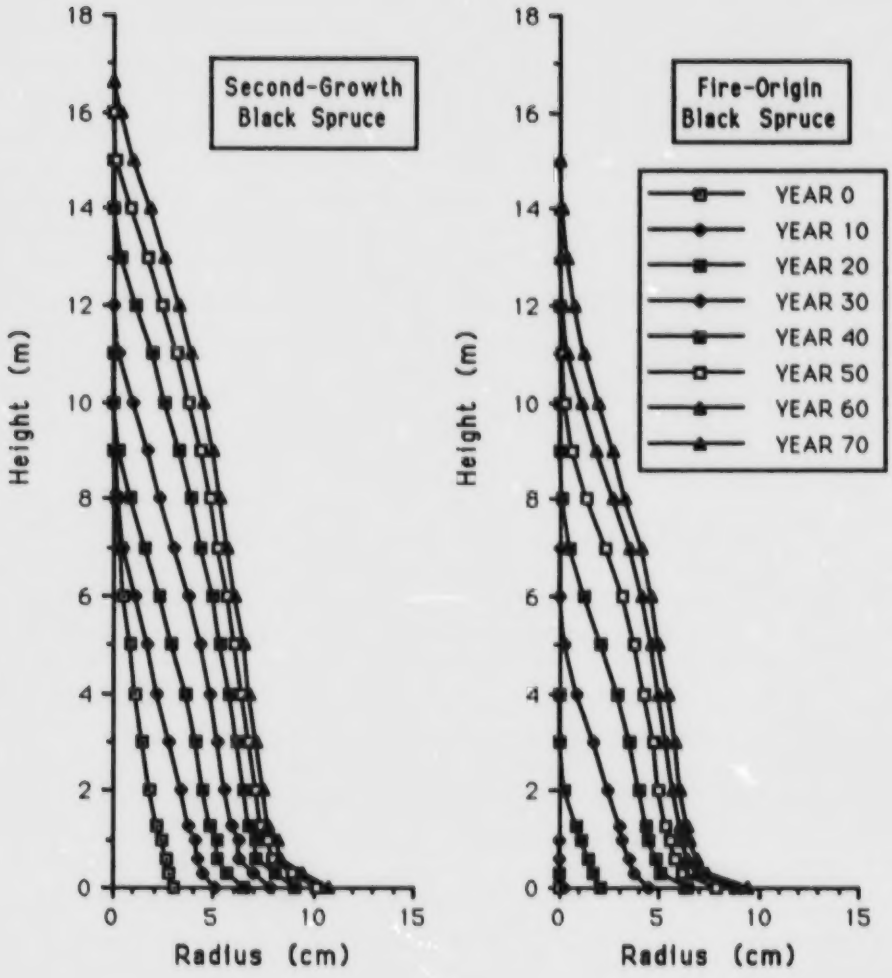

Figure VI: **Average stem profile of second-growth and fire-origin black spruce trees on mesic sites, high point density.**

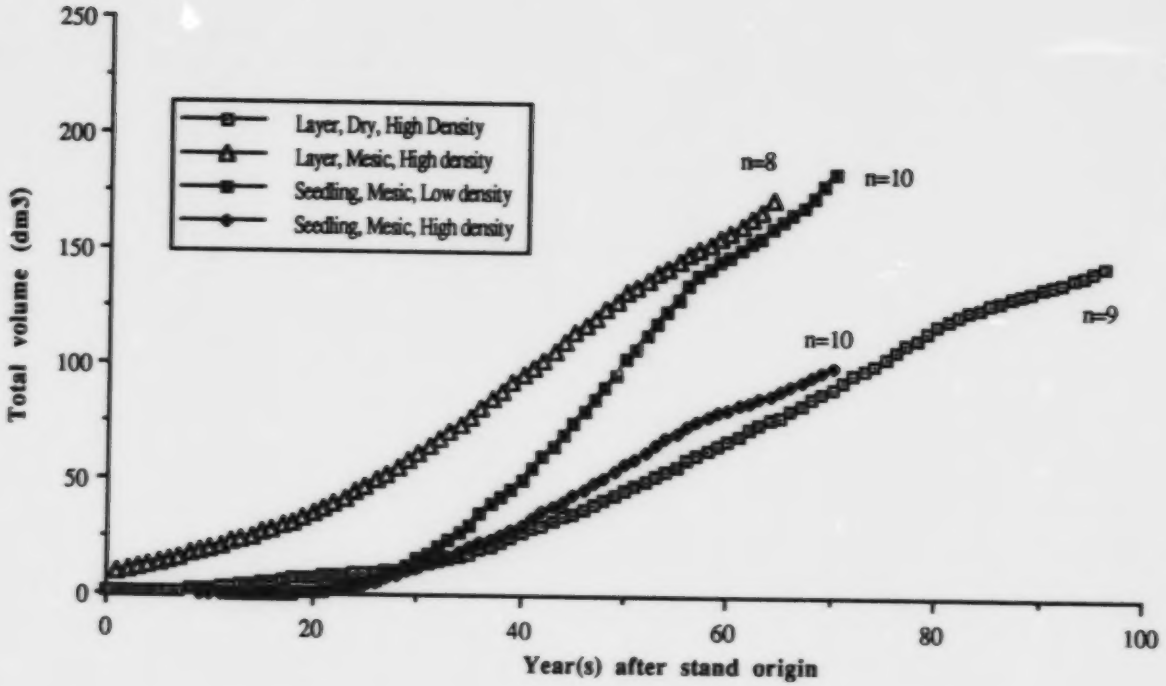

Figure VII: **Average height growth of fire-origin and second-growth black spruce trees in various site and competition conditions.**

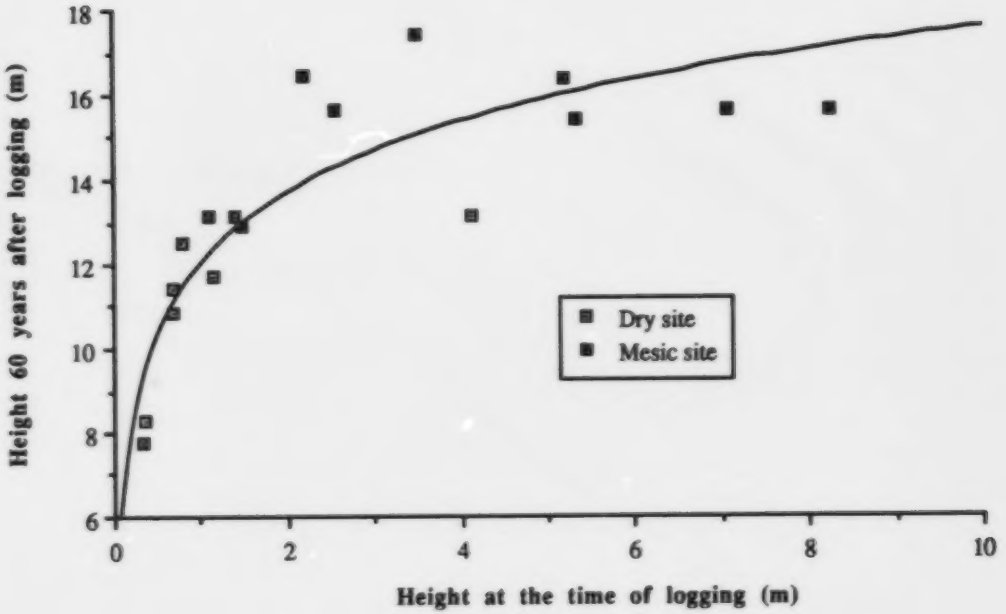

Figure VIII: **Relation between height of advanced growth at time of logging and height 60 years later.**

group comprised second-growth spruce trees growing on a dry site associated with a high point density, with a mean height of 1.19 m (STDEV = 1.16) at the time of harvest, in 1894. Since volume is highly correlated to height, a similar relation could probably be found between advanced growth height at the time of logging and volume at maturity. However, further work is needed to confirm these relations.

Impact of spruce budworm predation on black spruce growth is another interesting phenomenon on which our data could shed some light. Fortunately, the latest spruce budworm outbreaks in the Réserve faunique des Laurentides have been well documented by the work of Blais (1957, 1965, 1983) and by the Ministry of Energy and Resources of Québec, which could allow an evaluation of the extent and severity of the impact of outbreaks on growth.

The present work is obviously promising, and once the project is completed, it should give first-hand information on the performance and development of advance growth following logging which could greatly help forest managers attain their goal of sustainable yields.

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THE ESTABLISHMENT AND EARLY GROWTH OF RED SPRUCE AND BALSAM FIR REGENERATION

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ABSTRACT

During initial investigations of red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.) natural regeneration development, minute growth rings were discovered within seedling root collars. Because accurate aging of seedlings is essential in investigations of the timing of seedling establishment, a micro-measuring technique for microscopic examination of seedling root collars was developed and tested.

Using the micro-measurement technique and stem analysis procedures, the early growth of two spruce-fir sapling stands in Maine was reconstructed. Significant observations include verification that regeneration was predominantly established in advance of overstory removal and that early growth patterns of red spruce and balsam fir seedlings and saplings were remarkably similar. Additionally, the variable of seedling age as well as size was implicated as an important factor in predicting seedling response to release. This preliminary research defines a technique of tree measurement, and the two stand case histories suggest trends in the early development of red spruce and balsam fir that require further investigation.

INTRODUCTION

The complete chronology of a tree's growth from seedling to maturity is captured in the annual rings formed at the root collar. This morphological principal was the basis for using stem analysis to study the early stand development of red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.). During initial investigations of seedling development, minute growth rings were discovered within seedling root collars. These rings were not visible without the use of a microscope (Figure 1). Because accurate aging of seedlings is essential in investigations of the timing of seedling establishment, a micro-measuring technique for microscopic examination of seedling root collars was developed. Microscopic annual growth rings have previously been identified in suppressed balsam fir (Morris 1948) and other tree species (Tuberville and Hough 1939).

This presentation will focus on the development and testing of a micro-measurement (M&M) technique used to examine the period of annual ring growth between the seedling and sapling stages of tree development. Examples of how this technique was incorporated into a stem analysis study of the early stand development of spruce-fir will be illustrated.

DESCRIPTION OF THE MICRO-MEASUREMENT TECHNIQUE

Locating the root collar of a seedling within the bole of a sapling tree is difficult because the seedling root collar may be beneath the litter that has accumulated as the tree grows (Osawa 1986). Therefore, disks of the sample trees were cut out of the tree bole transversely at the soil line, and at centimeter intervals above and below the referenced soil line. Each disk was examined with a microscope for lateral roots and for changes in the number of growth rings.

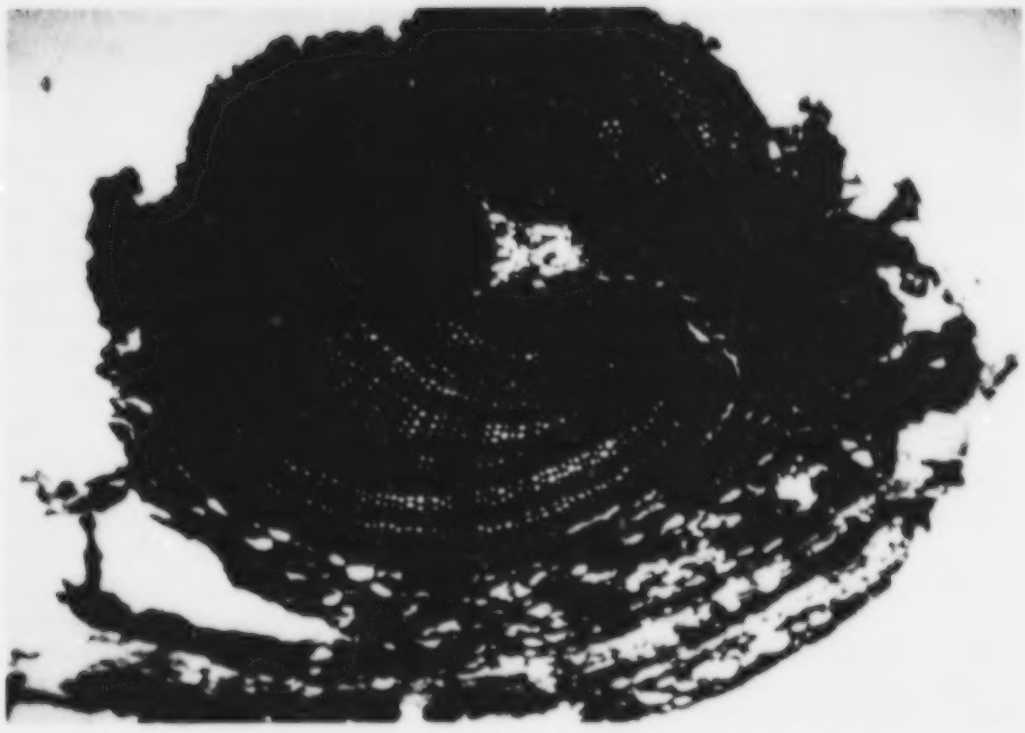


Figure 1 Micro-cross section of a spruce seedling showing the rings which are typical of saplings studied in evaluation of advanced regeneration. At least eight rings are visible within the 1.0-mm diameter of the root collar.

Once the seedling root collar was located, a sample block was extracted from the pith region immediately above the root collar disk (Figure 2). This block contained the growth rings of the sample tree when it was in the seedling growth stage. A sliding microtome was used to slice 20 micron-thick cross sections of the softened sample block (Berlyn and Miksche 1976). These sections were stained and prepared for mounting on microscope slides. Slides prepared in this manner offered a single cell view of the seedling ring growth at the root collar.

The growth rings of these trees were measured with a digital micrometer to the nearest 0.01 mm. Early seedling growth rings were measured on the microscope slides out to the last distinct ring. This last ring on the slide was matched to the same growth ring on the intact root collar disk. Growth ring measurements of ring growth were continued from this point on the disk along the same slide-disk radius. By transposing the microscopic slide on the larger root collar disk, an accurate ring count could be made.

TESTING THE MICRO-MEASUREMENT AGING TECHNIQUE

To determine if seedling growth rings were an accurate measure of a seedling's response to its environment, and that seedlings were not predisposed to growth ring abnormalities (*i.e.*, false rings, missing rings), several trees grown in controlled environments were examined using the M&M technique.

To test for the phenomenon of multiple ring formation in a single growing season, five red

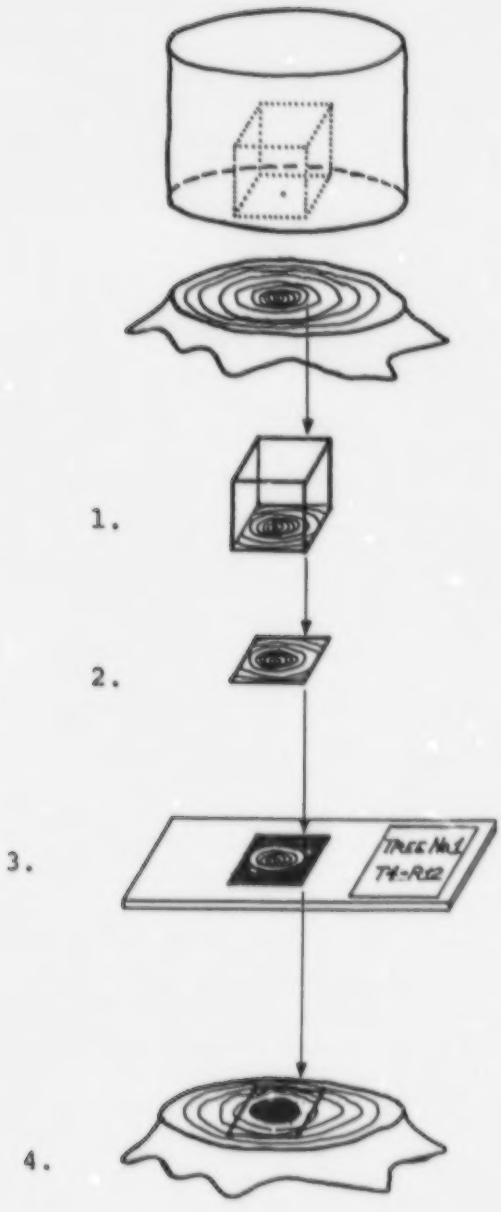


Figure 2 The extraction and measurement of seedling root collar growth documented in the annual growth rings of sapling trees.

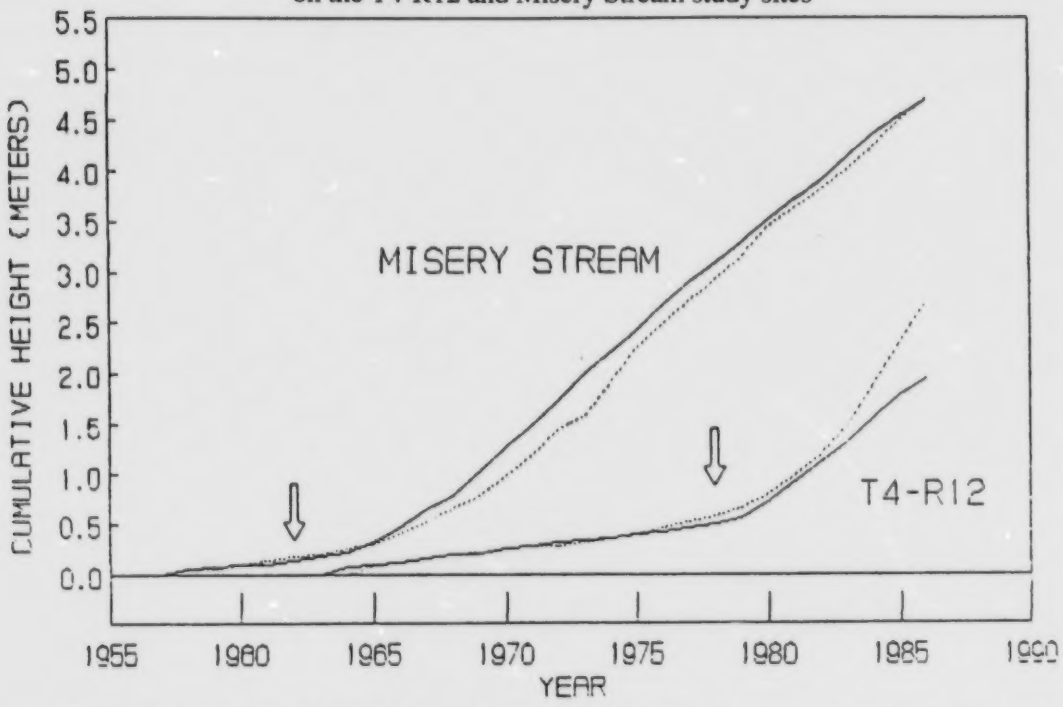
1. Sample block of root collar pith is extracted from the basal portion of a stem section.
2. A 20-micron thick slice is cut from the block, stained, and mounted on a microscope slide.
3. Early seedling growth rings are measured under a microscope up to a common ring.
4. The common ring is identified on the root collar disk and the remaining tree rings are measured.

spruce and five balsam fir nursery seedlings were analyzed using the M&M technique. For each species, the history of nursery culturing was known. Cross-sections of tree root collars for red spruce and balsam fir showed the formation of three annual rings, matching the numer of growing seasons for each sample group. A false ring was formed in the balsam fir when the seedlings were transplanted, but the abrupt disruption of cell growth caused by transplanting would require extreme changes in a natural environment. Such fluctuations are not typical in the northern temperate zone, and similar growth ring patterns were not found in any of the natural seedlings that were tested.

Another complicating factor in the comparison of artificial and natural regeneration is that luxurious greenhouse conditions stimulate multiple flushes of growth. The balsam fir seedlings grown in direct sunlight, frequently watered, and treated with fertilizers were reported to have had up to four flushes of growth in one growing period. However, the sampled balsam fir seedlings formed only one distinct ring per period. Given this observation, it does not seem likely that a seedling grown in the less luxurious environment of the spruce-fir forest would form a false ring.

The production of growth rings can be halted in trees undergoing severe suppression (Larson 1963). To test the effect of severe suppression on the occurrence of missing rings in seedling root collars, a plantation of suppressed white spruce saplings was examined. The plantation was established in 1936 on a recently harvested hardwood site. The competing hardwood vegetation was not controlled, and the plantation was overtopped at an early age. During 1987, eight sample trees from the suppressed plantation were located and sectioned at the root collar. These seedlings should have had two years of nursery culturing plus 51 years of out-planted growth, for a total age of 53. Ring counts of these seedlings ranged from 42 to 51, indicating that

Average Height Growth for Red Spruce (-----) and Balsam Fir (—)
on the T4-R12 and Misery Stream study sites



Average Root Collar Radial Growth (mm) for Red Spruce (-----) and Balsam Fir (—)
on the T4-R12 and Misery Stream study sites

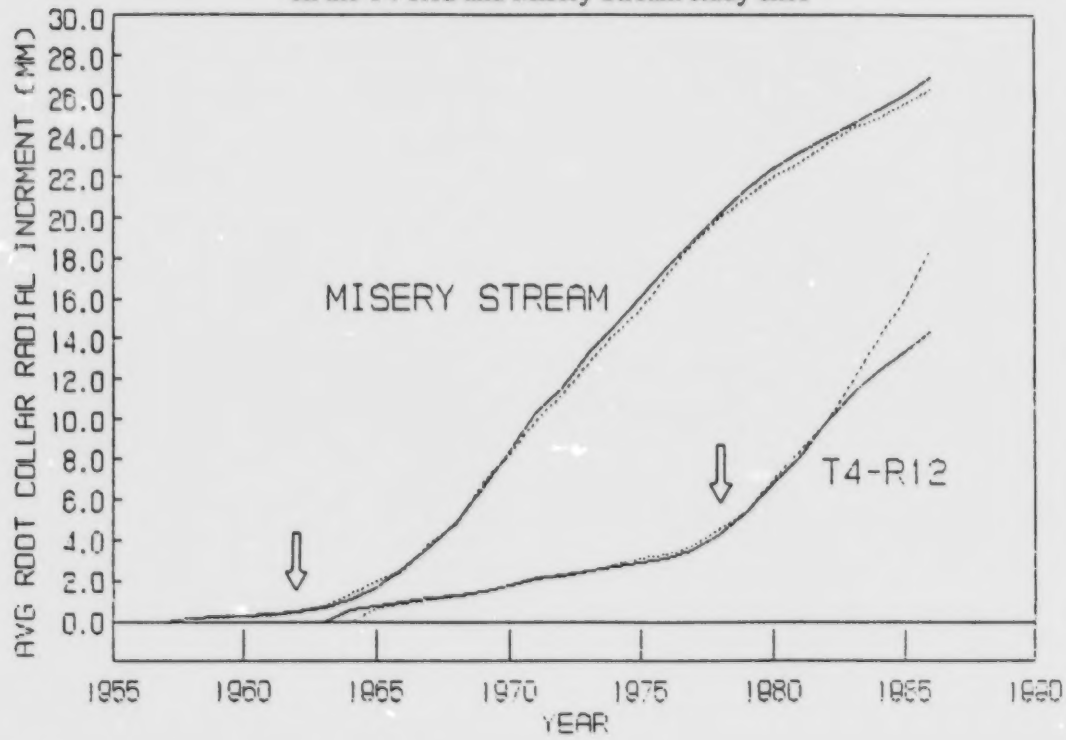


Figure 3

severe suppression does result in missing rings in the root collar region of seedlings. Further study is required to determine the degree of suppression required to suppress growth ring formation.

Incomplete rings were frequently encountered in examinations of tree cross sections. Examination of the complete cross section disk reduced this source of error. In general, measured ring counts of red spruce and balsam fir represent the minimum estimate of true tree age. Other species may have microscopic growth rings in the seedling phase of development, and they should be examined with the same level of precision. Although the M&M technique is time consuming, it is the only known way to precisely measure tree age and root collar radial growth.

OBSERVATIONS OF EARLY STAND DEVELOPMENT

Results from the stem analysis sampling of two spruce-fir sapling stands have been characterized as observations because random sample selections and a larger sample size were forfeited for the detailed measurement of a limited number of trees. Consequently, rigorous statistical analysis was not possible, but the following two case histories suggest trends in the early development of red spruce and balsam fir that warrant further investigation.

Two sites that had successfully regenerated to red spruce and balsam fir saplings were selected for further study. The first study site was located in Sandwich Academy Grant (Misery Stream), and the second site was in Township 4 - Range 12 (T4-R12). The Misery Stream study site was clearcut from December 1961 to March 1962 with a shortwood (4-foot) harvesting system and a snow cover of 2-3 feet. The average height of these saplings in 1986 was 4.5 m and tree density was 36 000 stems per hectare. A total of 14 balsam fir and 4 red spruce were sampled.

The T4-R12 study site was part of a strip clearcut operation cut in the spring of 1978 with Koehring Feller Forwarders. These strips regenerated very successfully to what is now a very dense thicket of saplings (89 000 stems per hectare) averaging 2.25 m tall. A total of 29 balsam fir and 7 red spruce were sampled in this stand.

At each site, two 2 X 2 m plots were established and all the trees in each plot were examined in each sapling stand. Stem analysis procedures were used at every .25-m loctaion within the first meter section of the tree boles. Internodal measurements of tree height growth were made beyond the 1.0-m mark. Root collar disks were cut and measured using the M&M technique.

Observation #1

Figure 3(a and b) illustrates that the majority of the seedlings that grew into saplings by 1986 were present as advance regeneration in the understory of the previous stand. Although three balsam fir seedlings (21%) on the Misery Stream plot were established in 1962 (two seedlings) and in 1963 (one seedling), the average age of balsam fir seedlings on this plot was 3.4 years at the time of harvest (Table 1). All of the red spruce seedlings on the Misery Stream site were established before the overstory was removed. All the red spruce and the balsam fir seedlings on the T4-R12 study site developed from advance regeneration. Trees on this plot averaged 13-14 years old when the overstory was removed.

This observation supports the importance of advance regeneration in the successful establishment of spruce-fir forests. Without careful examination of seedling growth rings, this fundamental relationship would have been overlooked.

Table 1 The average tree age at the time of overstory removal

Site	Spp.	N	Avg. Tree Age		Harvest		
					Tree Count		Period
			Release	1986	Pre	Post	(Mo/Yr)
Misery Stream	BF	14	3.4	28.4	11	3	12/61 –
	RS	4	3.7	28.8	4	0	3/62
T4-R12	BF	29	13.9	22.9	29	0	4/78 –
	RS	7	13.4	22.4	7	0	5/78

Observation #2

The second observation illustrated in Figure 3 (a and b) is that the average height and radial increment growth curves for red spruce and balsam fir are very similiar. Despite balsam fir's competitive advantage during the germination and establishment periods of development (Place 1955), observations of growth in this study provide no evidence that red spruce has an inferior rate of growth in the seedling and sapling stages of growth.

The limitations of stem analysis are apparent in this discussion because there is no way to reconstruct the influences of mortality or competition. For example, red spruce and balsam fir may have similar growth rates, but when individual spruce trees lapse into the lower crown classes, they rapidly die. In Figure 4, this hypothesis is illustrated when averaged patterns of growth for the trees on the T4-R12 plot are classified by 1986 sapling height classes. Within these classifications there are no red spruce seedlings found in the lower crown classes. This hypothesis can only be tested by observing stand development forward through time.

Observation #3

Sample trees were examined to see if there was a correlation between seedling height and root collar diameter at the time of release and the future sapling height and root collar diameter. In Figure 4, seedlings in the dominant height class at the time of release are shown to maintain their status and become dominant saplings. The small sample size of red spruce precluded any meaningful regression analysis. On both study sites, the variables of balsam fir seedling height and root collar diameter were statistically significant ($p < .05$) predictors of future sapling dimensions indicating that dominance of a tree may be expressed early in the seedling stage of development. However, the limited strength of this relationship indicated that other variables might be involved. With continued research, it may be possible to select superior crop trees at the seedling stage of stand development.

Observation #4

Sample trees were examined to see if seedling response (height growth) to release is a function of seedling age and size (height and root collar diameter) at the time of release. Westveld (1931) identified a function of seedling age and height as being important factors in the response of regeneration to release (Figure 5). Westveld illustrated that the taller and older a seedling is, the greater its response to release, up to a point where age has a deleterious effect on tree growth response. Results from a limited sample of balsam fir seedlings in this current study indicated that, while all three variables had a positive effect on seedling growth response, release age appeared to be a stronger predictor than seedling height or root collar diameter. While all these linear relationships were statistically significant ($p < .05$), low R2 values suggest that

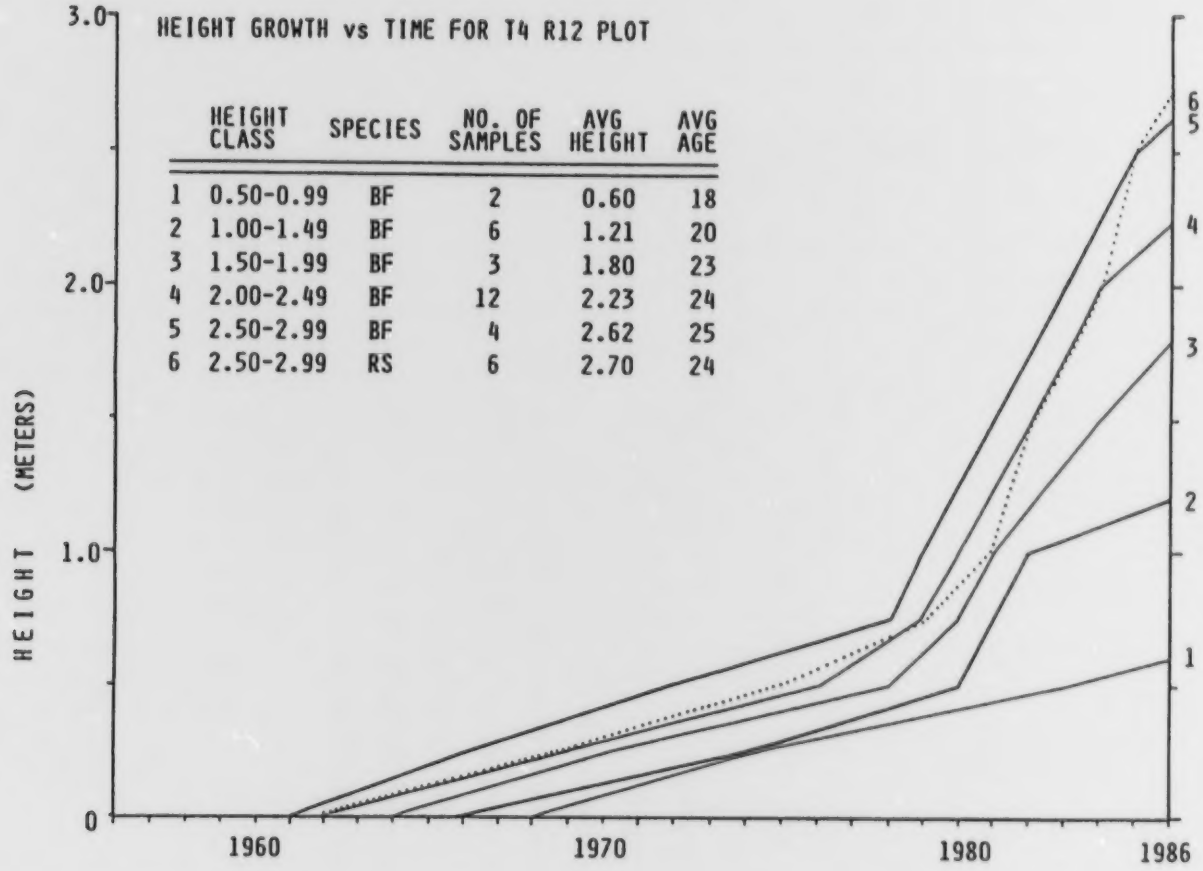

HEIGHT GROWTH vs TIME FOR T4 R12 PLOT
HEIGHT CLASS | SPECIES | NO. OF SAMPLES | AVG HEIGHT | AVG AGE
1 | 0.50-0.99 | BF | 2 | 0.60 | 18
2 | 1.00-1.49 | BF | 6 | 1.21 | 20
3 | 1.50-1.99 | BF | 3 | 1.80 | 23
4 | 2.00-2.49 | BF | 12 | 2.23 | 24
5 | 2.50-2.99 | BF | 4 | 2.62 | 25
6 | 2.50-2.99 | RS | 6 | 2.70 | 24
HEIGHT (METERS)
3.0
2.0
1.0
0
1960
1970
1980
1986
6
5
4
3
2
1

Figure 4

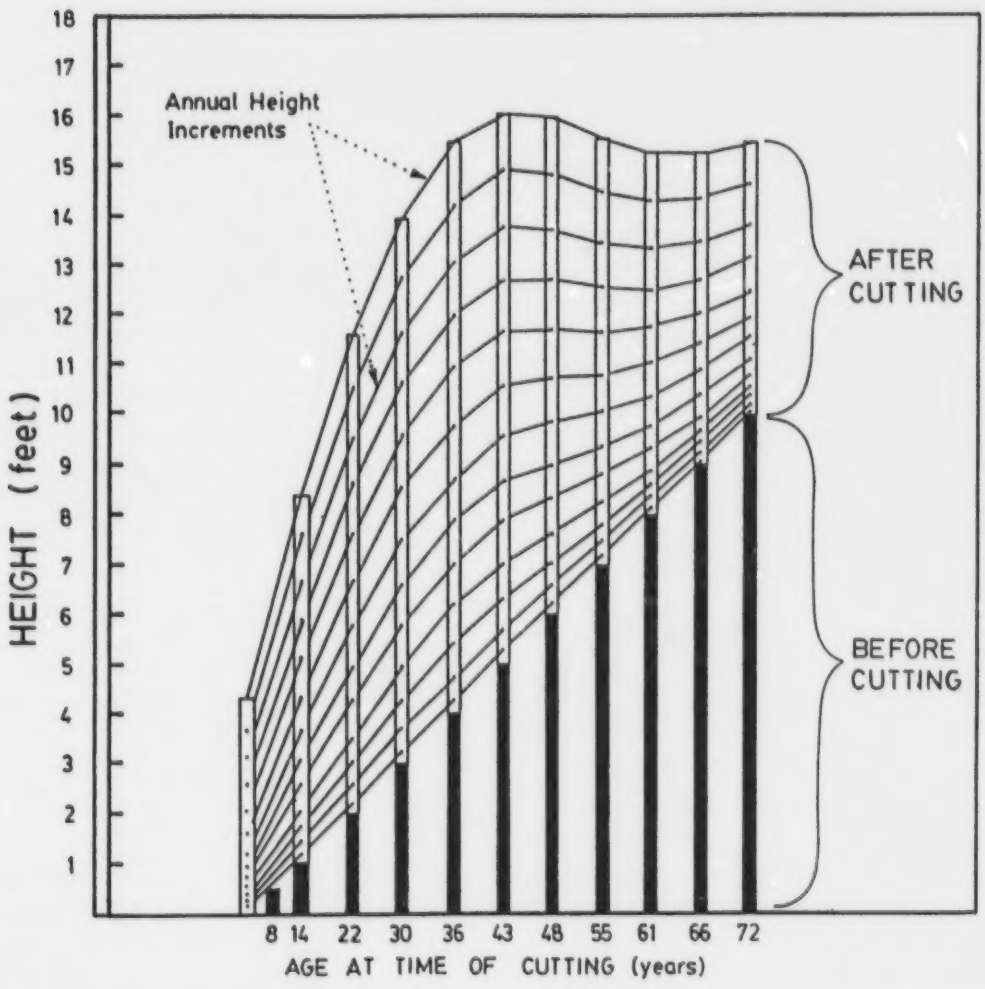


Figure 5 A modified chart by Westveld (1931) showing suppressed red spruce seedling and sapling height and age before cutting, and the subsequent growth for 13 years following cutting. The original canopy was dense, and all sampled trees were dominant (n = 62).

the majority of the variability is not explained by the model. It can be speculated that the importance of seedling age is significant in predicting seedling response to release, although the point where seedling age has a deleterious effect on growth response was not observed.

SUMMARY

Before useful field guidelines for the assessment of spruce-fir natural regeneration can be presented, further research is required. Stand reconstruction using stem analysis is very useful in oulining tree growth patterns throughout the lifetime of a tree. Care should be taken not to overlook the microscopic growth rings when determining the time of seedling establishment. However, to examine the influences of mortality, seedling crown dimensions, and species density, annual observations of a developing stand are required. Armed with the perspectives offered by both research approaches, silviculturalists will be able to examine the establishment and early stand development of red spruce and balsam fir, and guidelines for the assessment of natural regeneration can be constructed.

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THE ROLE OF ADVANCE GROWTH IN REGENERATION OF RED SPRUCE AND BALSAM FIR IN EAST CENTRAL MAINE

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ABSTRACT

Advance growth of red spruce and balsam fir occurs in a great abundance of ages, sizes, and shapes. While some of these forms appear to possess little capacity to respond and grow after release, in fact many can do so, and often grow rapidly within a few years of release. The use of large advance growth may be one efficient means of shortening the succeeding rotation and avoiding the "early successional hardwood stage" following regeneration. Silvicultural and logging implications are discussed.

INTRODUCTION

Research that formed the basis of this paper focused on balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) only. Conclusions presented here do not apply to white spruce (*Picea glauca*) or black spruce (*Picea mariana*); references to "spruce" in this paper refer only to red spruce unless otherwise specifically indicated. This paper is based on research and observations made in east central Maine, in and near the towns of Brookton, Kossuth, and Lakeville Plantation. Observations were limited to spruce-fir sites of average or better quality; stands in which my work was conducted contained no black spruce, sphagnum moss, standing water, or significant amounts of hardwoods. Thus, the best and worst sites were not included in my studies.

As has been ably documented in other papers in this symposium, red spruce and balsam fir regeneration are totally dependent on advance growth. If seedlings are not present at the time of overstory removal, then the species will not be present in the subsequent stand or, at best, will form an understory of suppressed saplings for a period of at least several decades.

FORMS OF ADVANCE GROWTH IN RED SPRUCE AND BALSAM FIR

Not all spruce and fir seedlings are created equal. Spruce and fir possess an abundance of advance growth forms. Red spruce, in particular, may well occur in a greater variety of sizes, shapes, and forms than any other species in North America. While spruce seems to be capable of enduring great suppression and then responding to release at almost any size or age during its lifetime, its advance growth seedlings and saplings tend to fall into three different groups based on height and shape: small seedlings, bushy large seedlings 0.3-0.5 m tall, and a severely suppressed umbrella-shaped form that is 1-3 m in height. Both spruce and fir tend to form the first category, the last category is comprised most commonly of spruce, and my observations suggest that fir is more abundant in the intermediate category.

The first category is usually ubiquitous under most spruce-fir stands in eastern Maine, often occurring in the thousands or tens of thousands per hectare. Although these seedlings are usually only 4-10 cm in height, they can be 5-10 years old (Osawa 1986, Strauch 1991). These seedlings may be rooted entirely in the litter layer, and thus are often vulnerable to death by drought if the overstory is removed entirely and the duff is exposed to desiccation by direct summer solar insolation. Even if they

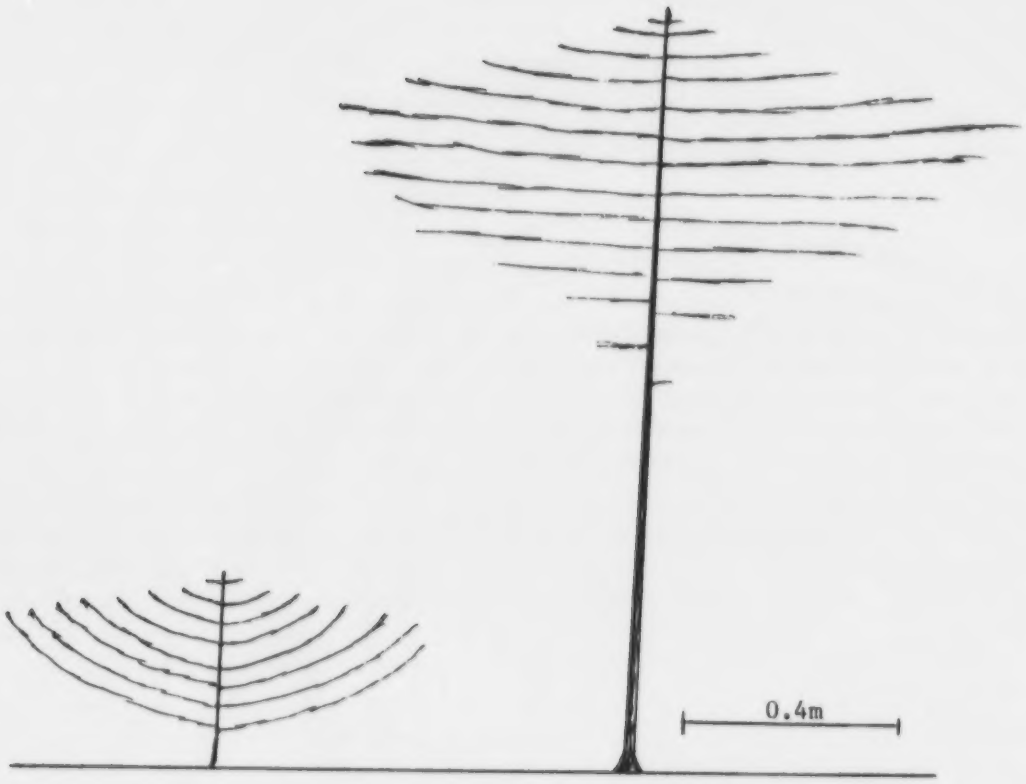

Figure 1 Idealized drawings of a candelabrum fir (left) and an umbrella spruce (right). Dimensions are roughly those of the mean values for samples of both forms of advance regeneration diseected in the course of reserach in east central Maine.

survive sudden release, these seedlings are subject to being rapidly and immediately overwhelmed by early successional species, such as raspberries (*Rubus* spp.) and red maple (*Acer rubrum*) and thus, on most sites, ought not to be counted on to furnish a new dominant spruce-fir stand after overstory removal.

The largest form of advance regeneration is one that Marinus Westveld, in his classic 1931 paper, dubbed "umbrella spruce", because of its side profile which in fact resembles an opened umbrella (Figure 1). These saplings can be from 40 to at least 80 years of age (aging can be uncertain because of missing rings in the most suppressed saplings), with crowns that are 1-3 m wide and 0.5-1 m thick in the vertical dimension. The saplings are 1-3 m in total height, with the bottom half to three-quarters of their boles being free of living branches, due to crown recession that occurs from the bottom up. They are formed when height growth slows to 1-2 cm per year, while lateral extension of the upper side branches continues at a greater rate. This growth pattern eventually produces a flat-topped sapling with a shallow crown that is wider than deep, and in fact often wider than the entire tree is tall. These saplings have an appearance that is so shaggy and decrepit that they traditionally have been ignored or over-

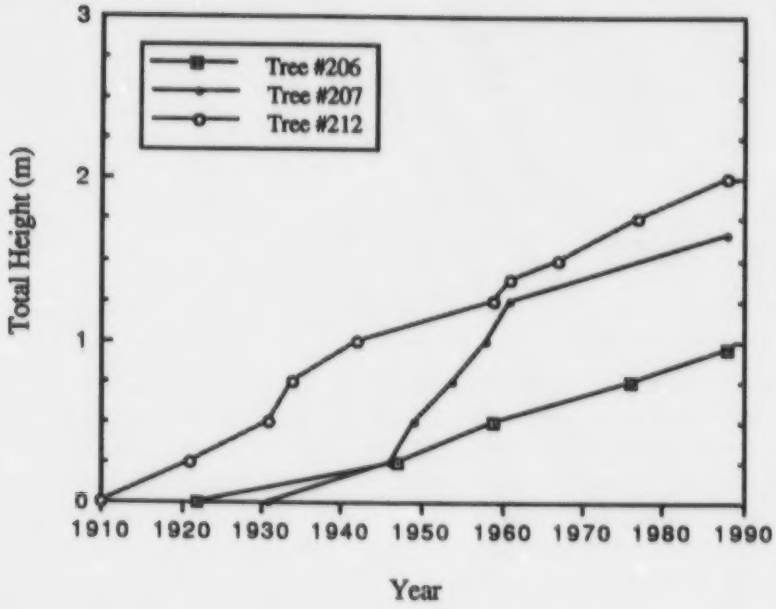

Figure 2 Height growth of three unreleased umbrella spruce saplings. Of the 15 umbrella spruces dissected, #206 was the smallest, #212 the largest and oldest (excluding three trees that gave evidence of missing rings in the lower half of their boles), and #207 the most nearly average with respect to age, size, and shape.

looked by foresters planning the regeneration of a new stand.

The intermediate category of advance growth is comprised of seedlings 0.3-0.5 m in height. The most common type of such seedlings is a fir with a crown wider than the total height of the seedling, and 15 to 40 years of age. As with the umbrella spruce, height growth slows drastically while lateral branch extension occurs at a greater rate. But in these smaller fir saplings, the longest branches are often at the bottom of the crown rather than the top, and they sweep upward to form a flat-topped crown like the umbrellas but with an entirely different branching structure. Since this morphology, with the longest branches at the bottom sweeping upward, resembles an elegant candelabrum, I refer to these saplings as "candelabrum fir" (Davis 1989). A schematic comparison of the size and shapes of umbrella spruce and candelabrum fir is shown in Figure 1.

Both of the larger forms of advance regeneration develop from the small seedlings described in the first category and discussed by Strauch (1991). The larger forms develop when some form of partial canopy disturbance allows greater light to penetrate to the forest floor for at least a few years. However, height growth of the umbrella spruce usually proceeds at a steady rate over a long period, rather than in a spurt followed by a total cessation. (See Figure 2, which shows the height growth of three typical umbrella spruces that were carefully dissected to determine height growth pattern.)

GROWTH OF DIFFERENT FORMS OF ADVANCE REGENERATION AFTER RELEASE

These larger forms of advance growth are so scraggly-looking and so obviously suppressed that their ability to respond and grow vigorously after release has traditionally been

Table 1 Summary statistics for the five sapling groups

Sapling group	Height at release (m)	Height growth 3 Yrs before dissection (m)	Height 11 yrs after release (m)
Released umbrella spruce	1.91 (0.94)	1.00 (0.27)	3.97 (0.73)
Tallest firs	0.35 (0.15)	1.37 (0.28)	3.81 (0.62)
Tallest spruces	0.3 (0.1)	1.06 (0.16)	2.66 (0.51)
Small firs	0.1 (0)	0.71 (0.44)	1.44 (0.67)
Small spruces	0.1 (0)	0.34 (0.21)	0.80 (0.44)

questioned by foresters. To determine the ability of relesed umbrella spruces to participate in the development of a new stand after overstory release, I dissected 15 former umbrellas in 1988 that had been released 11 growing seasons earlier by a conventionaly overstory removal. The 15 saplings were easy to locate in the cutover areas that had grown up in raspberry, aspen, birch, maple, and scattered spruce and fir saplings. The 15 released umbrellas were the only conifers on the sites whose narrow spired crowns projected into and occasionally above the canopy of the sea of early successional hardwoods; it was only after approaching these saplings and parting the growth around their bases that it was possible to see the shallow tight clusters of large branches 1-3 m above the ground that had been the living crowns of the umbrella spruces when they were released. Stem analysis clearly documented the presence of "buried" cores of 40-80 narrow growth rings that had constituted the boles of the umbrella spruces.

Response to release by these 15 former umbrella spruces had been dramatic. After a delay of several years following release, growth of both height and diameter increased greatly, to rates that were roughly comparable to those of saplings of similar size but that had been released when much smaller.

I then wanted to determine more precisely how the growth of these released umbrella spruces compared to saplings that had arisen from advance growth of different sizes. I used two other nearby areas that had also been logged 11 growing season prior to my work, and in which many spruce and fir saplings of a variety of sizes now occurred. The 15 tallest saplings in these two areas were selected for stem analysis; all 15 were fir. For each of the 15 tallest firs, the tallest spruce within a 10 m radius was selected and similarly dissected. For each spruce sapling, a nearby fir of similar height was selected and dissected. For all saplings, height growth for each of the last five growing seasons was measured (along with total height), and a disk was removed at ground level and total (or nearly total) age, and both age and diameter at release were determined later in a laboratory using magnification to count and measure ring widths.

The saplings comprised five groups (of 15 each):

1. released umbrella spruces
2. tallest firs
3. tallest spruces (not umbrellas)
4. smallest firs
5. smallest spruces

Table 1 shows, for each of the five groups of saplings, total height when dissected (11 years after release), height at release, and total height growth during the 3 years preceding dissection. The average heights of the five groups are shown graphically for the 5 years preceding dissection in Figure 3.

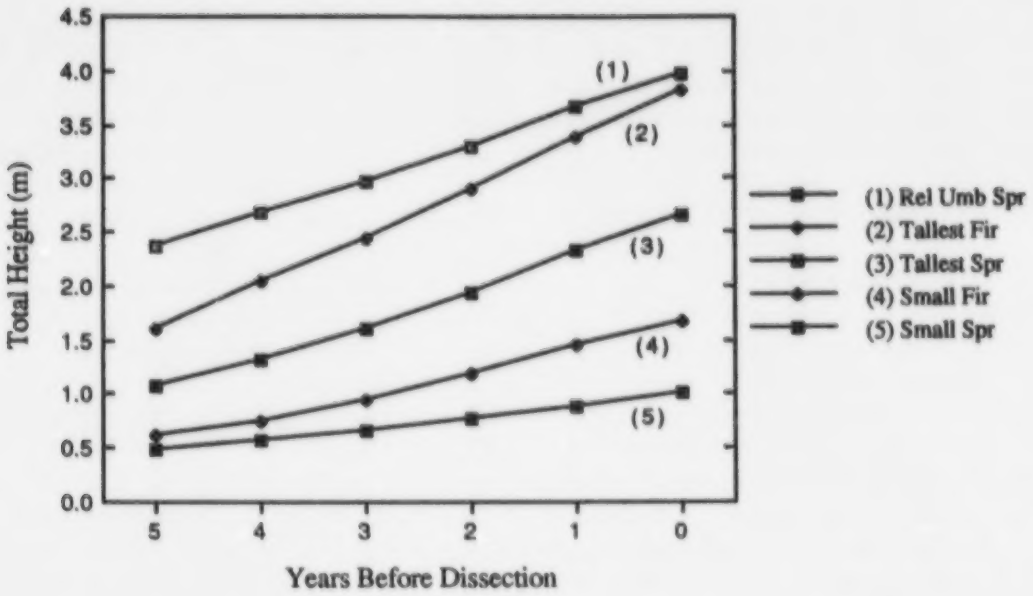

Figure 3 Mean height growth curves for the five categories of saplings. The five groups, from top to bottom, are (1) 16 released umbrella spruce; (2) the 16 tallest fir saplings; (3) the 16 tallest spruce saplings; (4) the 15 fir saplings that were 0.1 m or less in height when released; and (5) the 12 spruce saplings that were 0.1 m or less in height when released. All saplings had been released approximately 11 growing seasons before they were dissected.

After 11 growing seasons, the released umbrella spruces were still taller than the next tallest group (the tallest firs), although their growth rate the preceding 3 years was about a third lower than that of the firs, indicating that the firs would have surpassed the released umbrellas within only a year or two. The great advantage enjoyed by the released umbrellas over the tallest firs was primarily the result of their much greater height at release (1.91 m compared to 0.35 m for the firs). The released umbrellas were taller than, and growing at approximately the same rate as, the spruces that were 0.3 m tall when released; however, these smaller spruce saplings were shorter than and growing more slowly than the released candelabrum firs, which were of approximately the same height at release. Both the fir and the spruce saplings that had developed from seedlings only about 0.1 m tall at release were lagging behind the other three groups badly, both in total height and height growth rate.

Two results of this comparison are particularly worth noting. The first is that the umbrella spruces perform nicely after release compared to other categories of released seedlings, and in fact seem to be able to hold their own indefinitely against all but the released candelabrum firs. And even if these larger fir seedlings surpass the released umbrellas at some point, it is unlikely that a taller fir would ever truly overtop a slightly shorter neighboring spruce because of the narrowness of the fir's crown. The second important result is that height growth of the released candelabrum firs is impressive, both with respect to spruce saplings the same size at release, and to smaller seedlings of both species. This suggests that the conventional wisdom among Maine foresters that fir is more aggressive than spruce and grows faster after cutting (Bakuzis and Hansen 1965; Fowells 1965; Murphy 1917; Westveld 1931; Zon 1914) may be a function of the fact that candelabrum fir advance growth is relatively common, while

spruce is more usually present as smaller seedlings. A released small spruce seedling would stand slight chance of success when competing with a released candelabrum fir for dominance in a new stand.

ABUNDANCE OF RELEASED ADVANCE GROWTH FORMS IN MATURE STANDS

The next step was to determine whether these large forms of advance growth comprised any significant proportion of the mature second-growth stands that dominated the Maine landscape. These stands had originated from the budworm outbreak and logging of the period around 1920 and formed the dominant age class in the study area. In 1988, I conducted a survey of such spruce-fir stands in my research area to determine the importance of the various kinds of advance regeneration that had been the source of the present stands. Most of the mature conifer stands in the research area had been disturbed by recent cutting; therefore, nearly all of the undisturbed areas available for sampling were in uncut strips 25-50 m wide that had been left along the public highways.

Sixteen areas were sampled, which represented all the undisturbed stands in the area of which I was aware that met my overall criteria pertaining to site quality, species composition, and absence of recent disturbance. In this survey, I took advantage of the fact that certain important aspects of the developmental history of each tree are recorded in the pattern of branches that occur on the lower boles of fir and red spruce. Because fir and (especially) spruce shed their dead branches very slowly, the length, diameter, and location of a branch are discernible on a spruce bole decades after the branch has died. Thus, a very large branch indicates that it had been in favorable light conditions for at least some period before it died, and conversely a very small branch indicates that it had never been exposed to direct sunlight for any extended period of time. Vertical spacing between branches of 15 cm or more indicates that the seedling or sapling was growing vigorously in height when the branches were first created, while a patter of crowding or clustering of branches along the bole is produced when height growth is very slow, due to dense overhead shade. A lower section of bole that is entirely clear of dead branches indicates that the sapling had been in a state of such suppression that the lowest branches had remained so short and small that they fell off and healed over fairly quickly after the tree had been released and initiated more rapid diameter growth; the length of such a section of bole can be taken as a general indicator of the height of the suppressed advance growth when it was released. A schematic drawing of the lower boles of two mature spruce trees, one of which originated as an umbrella spruce, and the other which grew from a small seedling, is shown in Figure 4.

One plot was established in each area, with species, dbh, crown class, length of "clear bole", and a description of the dead branch pattern being recorded for each tree. "Clear bole" is a section at the base of the main stem that contains no branches (living or dead), no dead branch stubs, and no visible signs of branch stubs that have recently grown over. The presence or absence of a branch pattern indicative of the umbrella condition, or other condition of previous arrest, was also noted for each tree. The defining criterion of a former umbrella was the presence of a crowded cluster (at least four "whorls" deep) of large branches immediately above a basal section of clear bole. The length of clear bole was noted on all trees, whether associated with an umbrella branch cluster or not. In all, 320 trees were tallied: 267 red spruce (three of which were dead) and 53 fir (including five dead).

The results of this inventory technique were striking. At the time of their release, more than three-quarters (77.9%) of the spruces in my

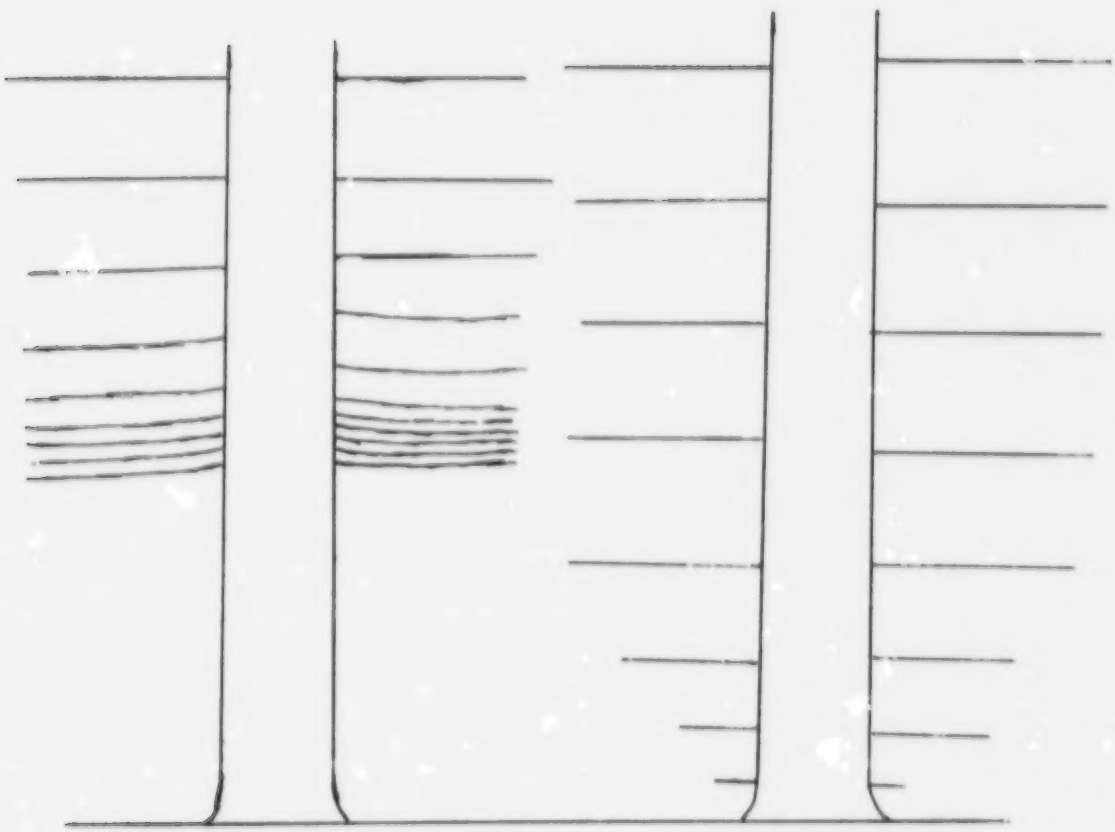

Figure 4 Drawing demonstrating differences in dead branch patterns on the lower boles of mature red spruce trees. Left: a spruce that originated as an umbrella spruce. The "clear bole" is the lowest portion of the bole with no branches. The cluster of branches immediately above the length of clear bole was the living crown of the umbrella spruce before it was released. The bottom of the branch cluster marks the base of the live crown when the sapling was released. Right: a spruce that was released as a small seedling and was free to grow. The distance separating branches is an indicator of its height growth rate.

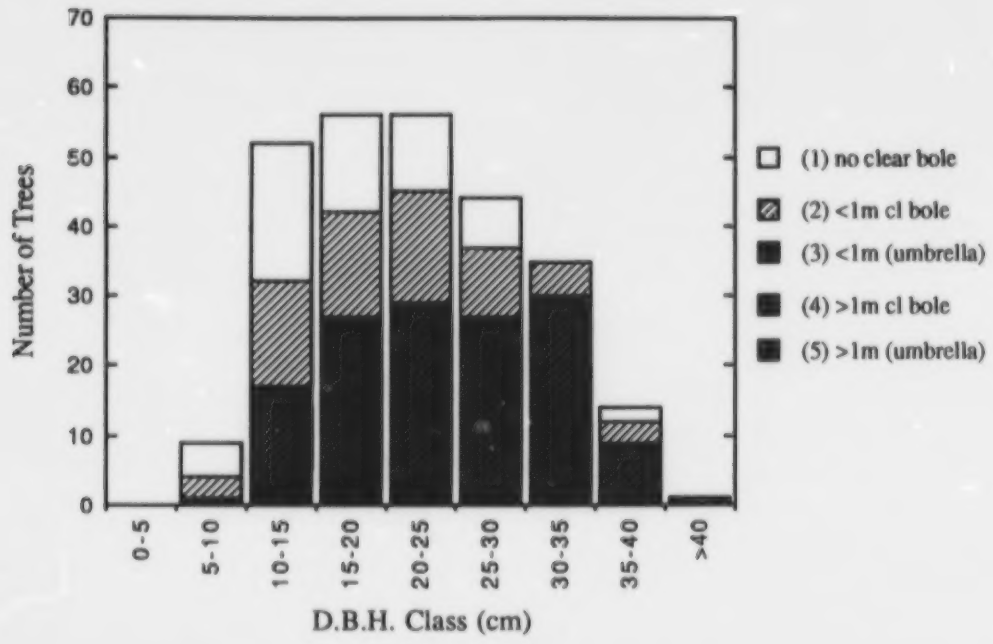

Figure 5 Length of clear bole and presence of former umbrella spruces in undisturbed spruce 60-80 years after release. Trees were classified in five groups: (1) those having no clear bole, but with branches visible all the way to the ground; (2) those trees having some clear bole, but less than 1 m in length; (3) same as (2) except that the tree also has an umbrella branch cluster present; (4) those trees with clear bole greater than 1 m in length; and (5) same as (4) but with an umbrella branch cluster present.

sample had grown from large forms of suppressed advance growth, with some length of clear bole. Furthermore, half (49.8%) of all the spruces had developed from the largest categories of advance growth, having more than 1 m of clear bole at the time of release (Figure 5). Former umbrella spruce comprised 10.5% of all spruces sampled, but they were less numerous than the forms that had not been so completely suppressed.

The spruces that arose from the largest category of advance growth are particularly significant in the larger diameter classes in the stands today, but they comprise but a small portion of the smaller diameter classes. Well over half of all stems larger than 25 cm dbh today have a meter or more of clear bole; these stems combined with those that arose from large umbrellas (with clear boles a meter or more in length) produce a category that comprises over three-quarters of all spruces larger than 25 cm dbh today. These are the stems currently merchantable as sawtimber.

Less than a quarter (22%) of the spruces had grown from advance regeneration that was quite small at release, with evenly spaced branches persisting along the entire length of the boles. Conversely, a majority (60.4%) of the firs had arisen from very small advance growth (Figure 6). Of the 21 firs (39.6%) that had been larger advance growth at release, only five (9.4% of the sample of firs) had a meter or more of clear bole.

All three of the firs larger than 25 cm dbh developed from small advance growth, as none had any clear bole whatsoever. No umbrella branch patterns were found on any of the firs examined.

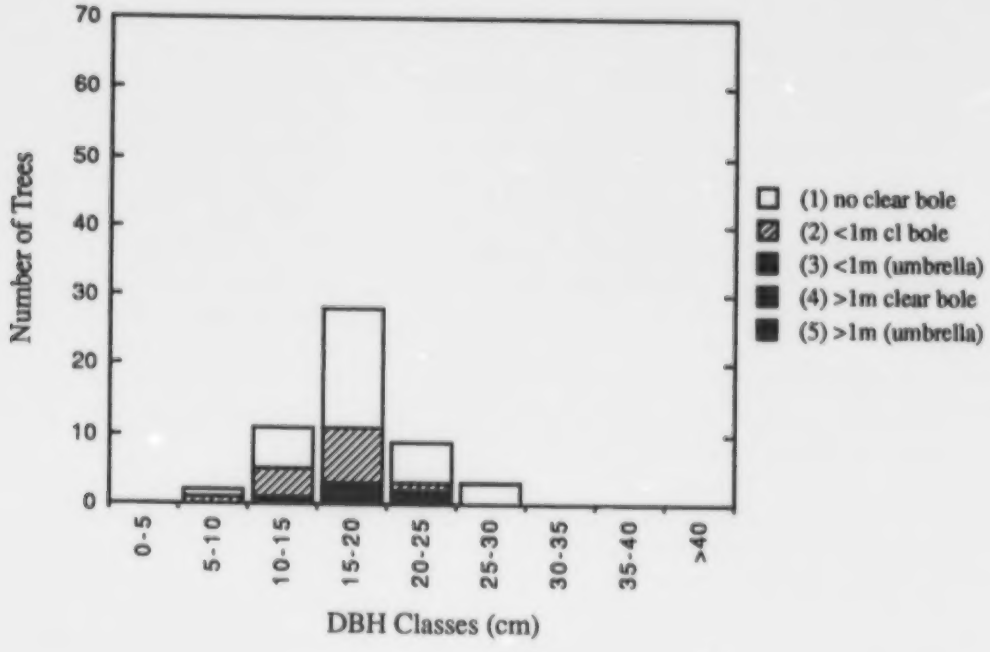

Figure 6 Same as Figure 5, except for the smaller sample of balsam fir.

DISCUSSION

Diversity of potential stand structures

Because of the diversity of spruce and fir advance growth forms, and the number of different kinds and intensities of disturbances that can cause regeneration of spruce-fir stands, spruce-fir forests are characterized by an unusual diversity of stand developmental pathways and resulting stand structures. Interpretation of stand history is difficult and will take a skilled eye developed from abundant careful observation and data gathering. This is unlike many species with ecological characteristics that cause them usually to be found growing in a small number of relatively simple stand structures (*e.g.*, the aspens, loblolly pine, and paper birch).

Spruce and fir might be thought of as unusually plastic or "forgiving" species; they are able to respond to and take advantage of a large number of kinds and intensities of overstory disturbances and produce advance growth that will participate in the development of the next stand.

Devising silvicultural systems consistent with spruce-fir ecology

The resilience of this vegetation type affords the silviculturalist an unusual breadth of options in managing and regenerating spruce-fir stands. The silvicultural system that may actually best match red spruce and balsam fir's ecological requirements is one that would have as a central objective the maintenance of stands permanently containing two or more age classes. This would be effective with these species because both are quite tolerant and are capable of producing these large, persistent forms of advance growth. Spruce and fir also grow relatively slowly when young, and live in a world where they are forced to compete with more aggressive early successionals such

as *Rubus*, pin cherry, and the birches and aspens that become established following significant disturbances. Spruce and fir therefore would be favored by a silvicultural system that involves a recurring series of partial cuts that release large advance growth and creates an environment conducive to the growth of a new age class of large advance growth while eventually choking out seedlings of the intolerant competitors.

This scheme would satisfy all the ecological requirements of both species, plus have the following advantages:

1. would accommodate the different life-spans of the important species;
2. would periodically clear out the fir which dies young anyway;
3. would retain and thin the spruce or white pine which can live long, grow large, and become valuable sawlogs;
4. would minimize stand regeneration costs (*i.e.*, site preparation, planting, and herbicide application); and
5. would minimize productivity lost to *Rubus* and other early successional species.

The difficulties with this approach are several. The first and most serious is that logging in a stand containing two or more age classes invariably results in the destruction of a certain portion of the younger age classes, is more difficult to carry out, and is more expensive than high-grading or complete overstory removal with large machinery. This approach to stand manipulation will require logging equipment of a kind not currently generally available in Maine. Logging operations will have to be coordinated with silvicultural objectives for the stand. Equipment will need to be matched to the silvicultural objectives and stand conditions, rather than vice versa. The more complicated stand structure will make growth and yield forecasting more difficult.

This silvicultural approach would contain elements of both the shelterwood and selection systems. It would differ from the simple shelterwood system in that it would permanently maintain two or more age classes in the stand, and a given age class might be removed in more than just one or two harvests. This approach might best be thought of as an extended or irregular shelterwood system, or as one variant of the German Femelschlag system (Burschel and Huss 1987). It might best be described as a "Femelschlag with standards"; the standards would be older scattered residuals of species such as red spruce or white pine.

It would differ from the selection system in that the stands maintained would have 2-3 somewhat different age classes but clearly not be all-aged; they should in no way be confused with the "balanced all-aged" stands postulated by classic selection system theory. No particular diameter distribution would result from this approach. The stand would not be managed as a sustained-yield unit. Each stand would contain a discrete and limited number of age classes, each produced by a specific partial canopy disturbance. The stand would be manipulated according to the requirements and potential of the several age classes; stand management objectives would not include the creation of any specific kind of diameter distribution.

Advance Regeneration and logging equipment

Residual trees of the large sapling and pole sizes can be relied upon to produce a new stand only if they can be preserved during the logging that removes the overstory and releases the advance growth. In the days of horse logging, a great deal of advance regeneration survived intact during logging operations. The situation is more difficult now that most harvesting is accomplished with large rubber-tired skidders and tree-length skidding.

The situation with respect to candelabrum fir and spruce advance growth of similar size is more hopeful. Most skidders have sufficient clearance that they can travel over seedlings without damaging them so long as the seedlings are not directly in the path of a tire, and so long as logs are not dragged directly over them. In this regard, whole tree skidding is quite destructive of advance growth, as the tops do a thorough job of destroying seedlings as they are dragged across the forest floor. Winter logging with a substantial snow cover may be helpful in protecting advance growth the size of candelabrum fir.

A variety of logging equipment designed for thinning pole stands has been developed in the Scandanavian countries over the past several decades. Some of these kinds of machinery may prove useful in solving logging problems in the silvicultural approach proposed here. This machinery is not yet widely available or in use in this country, and is quite expensive to import, but it will likely become more available to forest managers in the next few years.

Desirable kinds of advance regeneration in managed stands

Both forms of large advance regeneration studied in this project, the umbrella spruce and candelabrum fir, develop during extended periods of dense shade. In that sense, they are suppressed. Therefore, they are probably not the best of all possible kinds of advance regeneration to attempt to develop consciously through silvicultural manipulation. It is likely that advance regeneration as large or larger than umbrella spruce, but which retained apical dominance and living branches most of the length of the bole, would respond more rapidly to release than umbrella spruce.

SUMMARY

There are few forests on earth that should be easier to regenerate than the Acadian Forest. Few show such a remarkable capacity for small trees to well up from beneath the stands and remain ready to respond to release at almost any stage of development.

Natural regeneration of red spruce and balsam fir depends almost entirely on advance growth established prior to heavy removal cutting. Some of the forms of trees that function as reliable advance growth are several meters tall and possess distinctive shapes and branch patterns. In east central Maine, merchantable spruce-fir stands that arose after the 1912-1920 budworm outbreak and subsequent heavy cutting of merchantable spruce pulpwood are dominated by trees that were stunted saplings or arrested in the pole stage at the time they were released. Stunted umbrella spruces and candelabrum firs have the capacity to grow well after release although growth forms with pointed crowns in less severe condition of release grow better. Some red spruce trees may require two or even three rotations of balsam fir to develop into mature trees of sawtimber size.

Reliance on advance growth of any size requires modification or change of existing skidding equipment and careful use of any such equipment. The objective should be to leave residual stands that are irregular in height with trees well distributed.

Most of the advance growth regeneration that produced today's merchantable stands had become established in vacancies created by previous partial cuttings or natural mortality in old stands. If younger, more fully closed stands are to be regenerated, there will be need for removing the overstory in two or more stages. Not only will this allow for the establishment of advance-growth regeneration, but it will also make more efficient use of balsam fir's inherently short lifespan, and red spruce's biological capacity to produce large boles of higher value.

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NATURAL REGENERATION ASSESSMENT METHODS FOR QUALITY AND QUANTITY

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ABSTRACT

There is no one best method of regeneration assessment. Eight basic methods are reviewed. Each has its place and the method to use is determined by careful evaluation of the kinds of information needed and the cost of conducting the survey. We lack information about what qualities and standards define a successful seedling in either hardwoods or softwoods. Age and size of seedlings are commonly cited, but other factors may be important as well. Learning lessons from planted seedlings may be beneficial.

INTRODUCTION

This paper first reviews the methods for quantitatively assessing natural regeneration and then examines what is meant by a quality seedling. Finally, it reviews the question of standards for defining adequacy of stocking.

Regeneration assessment has relied on two descriptive terms. "Seedlings per unit area" and "stocking," usually expressed as a percent, are related, but not completely synonymous. "Seedlings per unit area" is an estimate of a density. "Stocking" is a measure of the proportion of the area actually occupied by trees or seedlings of a given age. "Stocking" can also imply a standard or goal as in "full stocking." For example, a cut-over area may have an average of five thousand seedlings per acre, with one half having 10,000 seedlings per acre and the other having none. This stand would only be 50% stocked.

Assessing Quantity

Quantitative assessment of regeneration is determined by the landowners or examiners goals. Assessment of quality is determined by answering the question of "What constitutes an acceptable seedling?" That will be discussed later.

There are eight methods of assessing regeneration (Stein 1985). These are outlined in Table 1 and in the appendix. Frequently, combinations of the various methods are used by landowners to achieve more than one objective.

No one method is best. Determining the method to use depends on careful and thoughtful evaluation of the purpose of the assessment (Stein 1985). This requires four steps. First, a clear definition of the kinds of information needed. Is stocking the only thing needed or is density required as well? This will determine the method and the intensity of the survey. Second, what are the stocking goals? The answer to this question may determine the size of the plot and define full stocking. Third, determine the size of the area that constitutes a void. Fourth, determine what constitutes an acceptable seedling.

Reconnaissance of an area is used frequently and informally; its value should not be under-

Table 1 Evaluation of Basic Methods of Regeneration Assessments

Method	Where used	Kinds of information	Constraints	Voids	Competition
Recon.	general assess.	qualitative	none	present	qual.
Distance	ecolog. studies	density	mod. dense stands	present location	identified
Variable Plot	varying heights	height selection	height variation	no	identified
Staked Plot	treatment effects	indiv. changes	none	no	identified
Plot Count	density	density	time consuming	mapped	measured
Stocked Quadrat	stocking	stocking	cover entire area	mapped	none
Sequential	plant. decision	stocking	prestratify	no	none
Aerial	general assess.	stocking & density	seedling height, timing	mapped	identified

estimated. Although it cannot provide numerical or statistical evaluation of a site, it provides a great deal of information to the experienced observer. A qualitative assessment of the size, vigor, health, species, and competition can be made. Adequacy of density and stocking can be judged, but this depends on the observer's experience. Voids can observed, but not located. Ground conditions and other environmental factors that play an important role in making decisions about a particular site can be observed. If questions arise about the area, then quantitative methods described below can be employed.

The disadvantages of this method are that it is time-consuming and an observer should cover the complete site or be confident that what has been observed reflects the whole site. Also, much of the judgement about the site depends on the experience of the observer. Plot count methods use a series of systematically laid out temporary plots in which acceptable trees are counted. This method is used primarily to determine density of seedlings. If enough plots are established in an area, stocking and voids can also be determined. Plot size and shape are not critical in determining density. The practicality of small plots is valued in dense stands, so that little time is spent on any one plot and more area can be assessed. Plots that are too small can lead to underestimates of density in light or medium stocked stands. Typically plot sizes of a milacre (0.0004 ha) or 4 milacres (0.0016 ha) have been used in the U.S. Density is then estimated and represented by the average number of seedlings per unit area.

The distribution of number of seedlings per plot is not normal and is usually skewed towards fewer seedlings per plot. In this case, the median and the mode statistics are more representative of central tendency than than the mean. However, extrapolating those to represent per unit area figures can be difficult. The Poisson distribution may be more useful when dealing with these kind of distributions.

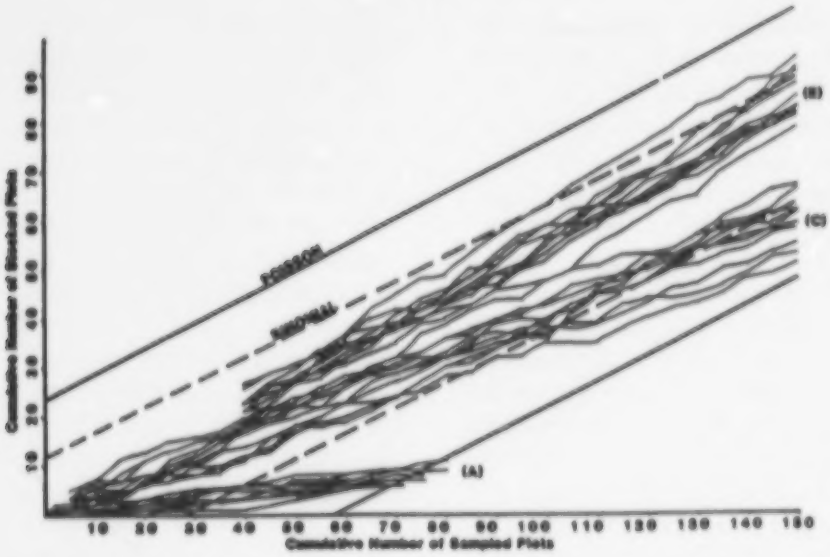

Fig. 3. Results of 10 trials of simple random sequential sampling on each of three recently harvested sites (A, C, and D).

Figure 1 An example of the use of sequential sampling. (Copied with permission of the author, from Fairweather 1985)

However, research needs to be done to develop the parameters of the distribution for varying size plots and seedling distributions. The higher the lambda parameter, the more normal the distribution.

$$f(x;l) = (e^{-1})*(l^{x}/x!) \text{ for } x = 0,1,2,...$$

where

l = lambda parameter, and
x = trees per plot

Stocked quadrat methods have been used to determine stocking and the distribution of regeneration for nearly 60 years (Stein 1985). It was originally based on the use of square plots, hence the name "quadrat." Circular plots can be used and are often easier. Plot size is determined by the reciprocal of the number of stems per acre (hectare) that constitute full stocking. This method is frequently misused because preliminary decisions about full stocking standards and sample size are often not made. In the field, the presence or absence of seedlings in a well distributed number of plots is recorded. The percent stocking is then easily calculated. For example, if 500 trees per acre is considered full stocking, then 1/500 of an acre is used for a plot size. Areas that cannot be stocked, because of rocks or water, are usually disregarded in the calculations.

Stocking can either be overestimated or underestimated if the reciprocal of full stocking is not used. If too large a plot is used, the estimate of stocking is likely to be high, because the probability of presence of a seedling is higher. If too small a plot is used, stocking is likely to be underestimated (Stein 1985).

Sample size is determined by the specified confidence interval, the product of an advanced estimate of the stocking percent and 100 minus the stocking percent, and the error to be tolerated in the final estimate of the stocking percent (see appendix). For example, if 95% confidence interval is used (using 4.0 in the equation), the advanced stocking percent is estimated to be 50% and the error term

is 10%, the number of plots required is 100. These 100 plots would then be distributed throughout the area of interest. If the area were 40 acres, it would require 2.5 plots per acre.

Sequential sampling has been developed since World War II. It can be used to help determine whether an area that is marginally stocked should be planted or should receive another treatment (see Figure 1). A thorough review of the procedures is offered by Fairweather (1985). Prior to sampling, probabilities of Type I and Type II errors are determined. (Type I occurs when an area is mistakenly classified as understocked; Type II error occurs when an area is misclassified as adequately stocked.) Acceptable and unacceptable stocking levels are determined. Finally, the anticipated distribution of seedlings is determined.

These factors are combined to form a decision chart. Samples are taken on small plots and presence or absence of seedlings are plotted in the field against the number of plots sampled. Once the lines drawn cross the predetermined lines, then sampling stops and decision can be made.

This process helps the user make the decision to proceed to follow-up treatments. Also, it requires fewer plots than the stocked quadrat method. However, it is premised on collecting random samples from a homogeneous area (Stein 1984). The area needs to be specified ahead of the sampling. Also, theoretically, sampling could go on forever. As a practical matter, stopping the sampling before an area is well covered, leaves the condition of the rest in doubt (Stein 1984).

Staked point methods are used principally to examine changes to those permanent locations over time or following various treatments. This method requires permanent marking of trees or plot centers. Within the plots, individual trees may be marked for consideration. This flexible system has the disadvantage of being tied to a specific set of treatments. Sampling and sample size are not related to the area in question, but to the treatment(s). This information cannot be combined with other studies without ensuring that similar sampling schemes were employed (Stein 1985). Because the plots are usually established where seedlings occur, voids are impossible to detect.

Distance methods have been used in ecological studies of vegetation communities. They involve measuring the distance from a sample point to the nearest acceptable seedling and/or its nearest neighbor. Density is calculated as the inverse of the distance between seedlings (Batcheler 1971). This method determines the adequacy of stocking, since the sizes of open spaces are actually measured. By plotting the openings greater than a specific size, voids can be mapped. There is a practical limitation to how far an observer will go to measure the nearest tree or its neighbor. This introduces biases in the estimates of density. Also, biases are introduced when distribution of seedlings deviate from perfect randomness, as they often do. In an "aggregated" or "clumped" distribution, distance methods have underestimated density. In uniform distributions, such as plantations, density is usually overestimated (Fairweather and Amrhein 1989).

Variable-plot methods based on heights have been selectively tried (Beers 1974; Fairweather 1990, personal communication). The method, similar to prism cruising, uses projected angles to select seedlings. Based on seedling height and the angle, estimates of plot area, tree factors, etc. are made. However, the height factor, in feet or inches per acre (hectare), unlike the basal area factor has little empirical meaning. This method also has little usefulness if the seedlings are small, as they would be shortly after an area has been harvested or planted.

A thorough examination of the cost and accuracy of several of these methods is offered

by Kaltenberg (1978). He applied fixed area, distance and polyareal sampling rules to simulated stocking and density at three different levels. He found that distance rules produced biased estimates of density. Polyareal methods (variable plot) accurately predicted density, but provided no estimate of stocking. Fixed area rules (stocked quadrat and plot count) provided accurate estimates of both density and stocking.

Large-scale aerial photographs have been used by some agencies in remote areas, to make general assessments of stocking and density and to map voids for later planting (Ball and Kolabinski 1979). Many areas can be covered in a single flight and questionable ones can be examined later. Also much of the work can be done in the winter. Color infrared film enhances identification of softwood seedlings.

However, the timing of the photography is critical and for softwood is generally limited to leaf-off, no snow periods. Photographs of the scale 1:500 are needed to see percent stocking of softwoods at = 30 cm (10 inches) and scales of 1:500 to 1:1000 to see conifers at = 1 m (3.3 feet) (Ball and Kolabinski 1979). The problem is that some cutover areas would be several years old and options for reforestation would be limited. Authors have recommended multi-stage sampling with one or more aerial photographs and ground surveys to determine final plantation sites (Kirby 1980). Hardwoods are even more difficult to detect by species (*e.g.*, if maple were to be distinguished from aspen).

Satellite imagery has been tried with some success. Summer Landsat imagery could not be used to identify some stocking and age classes with high accuracy (Sader 1989). Leaf-off imagery was to be investigated to determine if accuracy standards could be improved. This system is highly dependent on sophisticated equipment, trained personnel and timely images.

Combinations of methods are frequently used to develop different kinds of information. Stocked quadrats and plot count methods derive information on both stocking and density. Different size plots may be used for different seedling sizes or different age classes. Aerial photography could be used to determine homogeneous areas within a regenerated stand, followed by sequential sampling to determine need for planting. Again, the choice of methods is determined by the kinds of information needed.

Quality or What is an Acceptable Seedling

The literature is devoid of detailed information about qualities of natural regeneration. Over the years, there have been many published regeneration assessments in the northeastern U.S. and eastern Canada, mostly concerned with density and stocking of softwood regeneration following cutting. Westveld (1931), Long (1946), Bonner (1950), Vincent (1956), Hatcher (1964), Frank and Putnam (1972), Moore (1974), Randall (1976), Jablanczy (1979), Wall (1982) are but a few of the studies. There is little information about the qualities that make successful seedlings. I am defining successful seedlings as those seedlings that can successfully survival and grow into the sapling stage. Frisque *et al.* (1978) identified the best seedlings on study plots 10 years after harvesting using vigor and dominance. It would valuable to know the qualities of those "best seedlings". Hatcher (1964) found fir response after logging to be related to seedling age, height, and height growth at the time of release. Although vigor was not defined, for seedlings of equal vigor, the small and young seedlings outgrew the larger and older seedlings in height. In his study, trees in the 1 to 2 foot height class grew the fastest after logging. Westveld (1931) found seedlings that were moderately suppressed responded vigorously when released. The fastest growers were those that were 2 to 5 feet in height, with fir responding better than spruce. Marquis (1982) working with Al-

Table 2 A Suggested list of seedling qualities to examine to predict future survival and growth of natural regeneration.

Height
Root collar diameter (ground or at stump height)
Age (as determined by bud scars or whorls or nodes)
Seedling form (*e.g.*, "Umbrella spruce" vs pyramidal spruce)
Whether the seedling is free to grow
Position in the canopy or stand
Height: root collar diameter ratio
Number of secondary leaves (for hardwood)
Size of leaves, length and width
Leaf surface area
Terminal bud size
Number and size of lateral buds
Past annual height growth
Past annual diameter growth
Color of new leaves at maturity
Signs of injury
Origin, seed, stump or root sprout or layered
Size of original stump for hardwood sprouts
Site conditions

legheny hardwoods, recommended that advance hardwood seedlings achieve 3 or 4 years of age and 4 to 6 inches in height for best survival after clearcutting. Several authors at this conference (Belanger 1991, McInnes 1991, Davis 1991 and Lussier 1991) demonstrate research towards understanding what qualities determine successful seedlings. Knowing these qualities, we can then better define acceptable seedlings in regeneration surveys.

More is known about what qualities make a successful planted seedling and we might take a few lessons from here. Physiological characteristics are considered to be more important than morphological characteristics (Hallett 1985; Sutton 1979). However, physiological characteristics can only be assessed by destructive sampling and this leaves open the question of how the seedling would have performed. As a consequence, morphological characteristics are used. Hallett (1985) used seedling height, root collar diameter, seedling dry weight and shoot:root ratio when assessing containerized seedlings qualities. Mullin and Christl (1981, 1982) used morphological characteristics to grade seedlings and found that seedling height, root collar diameter and root volume were good indicators of performance after 6 years. We can also take lessons from Thompson (1985).

So, in Table 2, I offer suggestions concerning a place to continue the study in this area. Each of these qualities needs to be examined on a variety of marked individual seedlings under various conditions; then follow-up on the seedlings must be carried out for a period of 5 or 10 years.

STANDARDS

Having calculated stocking, the question then becomes, what does it mean? The stocked quadrat method is actually an indication of minimum density present. Usually density is much greater. Curves have been developed in

some areas that predict density from stocking percentages (Bever and Lavender 1955). These would have to be developed for a region working on similar forest types and conditions. Some curves have been developed for the Maritimes by Weetman and Frisque (1977).

If stocking falls below 100%, what are you the land managers going to do about it? The standards that some companies and agencies use are that below 40% stocking of milacre size plots, planting or seeding will be conducted. Above 70%, stocking is usually considered satisfactory. In between 40% and 70%, agencies usually wait to see whether natural regeneration improves the situation.

The USFS uses stocked quadrats surveys in the first and third year after harvest using a +/- 15% accuracy on the survey. Notes are also taken on environmental conditions, insect and disease problems and overtopping. Their standards for minimal acceptable stocking for natural regeneration system based on milacre plots are for aspen: 85%, northern hardwood: 40% or 60%, spruce-fir: 50% with two seedlings, and paper birch: 50% with two or three seedlings.

One company in Maine uses 1/550th of an acre (0.0045 ha) plot to assess regeneration with a 99% confidence interval at +/- 10%. The minimum standard is 70% stocking. At less than 70% stocking, voids are found in the area and are replanted if they are minimum of 5 acres and are less than 40% stocked (Champion 1987).

Another Maine company has used a combination of systems to assess regeneration. Using milacre circular plots at 2.5 x 3 chain intervals, numbers of seedlings are tallied by species. This is used to determine percent stocking and density of desirables for making a planting decision (Fairweather 1981).

For plantation assessment, policy on the Crown land in New Brunswick requires a circular 40-m^2 (approx. 1/100th acre) plot with a 90% confidence interval with increasing variation around the mean with increasing densities. For precommercially thinned stands, stocking needs to be greater than 50% with commercial species (NBDNRE 1989).

RECOMMENDATIONS

I offer the following recommendations regarding regeneration surveys and quality of seedlings. For the researchers, more information is needed on the morphological characteristics that point to seedling success. For a start, height, age, root collar diameter and low height:root collar ratio would be characteristics to examine. However, standards for these need to be developed for a number of species and conditions. Managers need to know, for example, how tall or how old seedlings need to be to respond well.

For land managers and examiners, I have offered the various methods of regeneration assessment. The choice of the methods to use depends on the kinds of information needed. There are a number of studies available which indicate density and stocking standards. I suspect that these have been arbitrarily set. I strongly urge that studied stands are reexamined several times for years after initial assessment is done to validate the findings of the original assessment. Empirical research which examines density and stocking at mid-rotation or rotation length stands would provide standards for natural regeneration that reflect natural conditions. This is similar to the work that Doucet (1991) reported in these proceedings. These standards would be hard to refute.

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APPENDIX

1) **Reconnaissance**
Where Used: general assessment
Kinds of Information: qualitative assessment, size, vigor, health, competition, future care
Statistical Reliability: none
Constraints: none, best to cover site
Sample size: none
Voids: presence or absence, not location
Competition: qualitative
Timing: anytime

2) **Plot Count**
Where Used: low to moderate dense sites, density is variable of interest
Kinds of Information: density
Statistical Reliability: inherent
Constraints: cover entire area, time consuming
Sample Size: $n = (4*s^2)/E^2$ (at 95% CI)
Voids: location, if mapped, and many plots
Competition: can be measured
Timing: when appropriate

3) **Stocked quadrat**
Where Used: stocking is variable of interest
Kinds of Information: stocking
Statistical Reliability: single number for site
Constraints: need to cover entire area, determine full stocking
Sample Size: $n = (4*pq^2)/E^2$ (at 95% CI)
Voids: location, if mapped and many plots
Competition: no information
Timing: when appropriate

4) **Sequential**
Where Used: in homogeneous sites to determine if planting is needed
Kinds of Information: stocking
Statistical Reliability: inherent
Constraints: prestratification
Sample Size: until a decision is made
Voids: used is questionable areas
Competition: no information
Timing: when planting decision is being made

5) **Stacked Plot**
Where Used: study treatment effects
Kinds of Information: changes in individuals
Statistical Reliability: inherent
Constraints: none, not related to area
Sample size: depends on the data to be collected
Voids: no information
Competition: can be measured
Timing: when appropriate

6) **Distance**
Where Used: moderately dense stands, ecological studies
Kinds of Information: density
Statistical Reliability: inherent
Constraints: moderately dense stands are best, prestratification is required
Sample Size: $n = (4*s^2)/E^2$ (at 95% CI)
Voids: presence and location, if mapped
Competition: identified
Timing: when appropriate

7) **Variable Plot**
Where Used: moderately dense stands with wide range of heights
Kinds of Information: height selection
Statistical Reliability: inherent
Constraints: moderately dense stands with height variation
Sample Size: based on angle used
Voids: difficult to assess
Competition: can be measured if height is major factor
Timing: whenever get height differentiation

8) **Aerial**
Where Used: general assessment of several sites with limited access
Kinds of Information: stocking and density, no numeric information
Statistical Reliability: none

Constraints: seedling height
Sample size: none
Voids: a ready map is made

Competition: can be generally assessed
Timing: critical, usually several years after harvest

THE INFLUENCE OF STOCKING OF REGENERATION ON THE YIELD OF NATURALLY REGENERATED JACK PINE AND BLACK SPRUCE STANDS[a]

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ABSTRACT

The exact location of all living and dead trees was determined in semi-mature jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) stands in order to estimate their stocking, as measured by the stocked-quadrat method, at the time they became established. Stocking was then related to actual yield at or near rotation age, by means of non linear regression. Good results were obtained for jack pine, but those for black spruce were less reliable because of inadequate sampling at the lower end of the range of stocking. This information will help the forest manager decide on the action to be taken when confronted with a given level of stocking of regeneration.

RÉSUMÉ

La position exacte de tous les arbres, vivants ou morts, a été déterminée dans des peuplements de pin gris (*Pinus banksiana* Lamb.) et d'épinette noire (*Picea mariana* (Mill.) B.S.P.) approchant de la maturité, afin d'estimer leur coefficient de distribution au moment de leur établissement. Un modèle de régression non linéaire a ensuite été utilisé pour relier le coefficient de distribution au rendement des mêmes peuplements au moment ou ils approchaient de leur maturité. Cette méthode a permis d'obtenir de bons résultats dans le cas du pin gris. La précision des résultats pour l'épinette noire s'est révèlés moins bonne, par suite d'une sous représentation des peuplements de densité faible. Malgré tout, les résultats obtenus vont permettre au gestionnaire forestier de prendre une décision mieux éclairée sur les actions à entreprendre, lorsqu'il sera confronté à un niveau donné de régénération dans les territoires à aménager.

INTRODUCTION

Establishment of regeneration is an essential step in forest management. It must be obtained as soon as possible after a major disturbance to capture all the potential of the site and to prevent encroachment of unwanted vegetation. So regeneration surveys are conducted early after disturbance in order to provide the forest manager with enough information for planning renewal activities. In Canada, regeneration surveys usually make use of the stocked-quadrat method (Alberta Forest Service 1979; Chaudry 1981; Paquet 1984; Manitoba Department of Natural Resources 1989). Basically, this method consists of determining the presence or absence of desirable seedlings in small sample plots (usually from 4 to 10 m^2) and computing the percentage of plots that are occupied. This percentage is the stocking of the area surveyed.

The stocked-quadrat method was apparently developed in the United States in the early 1920s (Lowdermilk 1927). Since then, much

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discussion and effort has been put into the matter of choosing an appropriate quadrat size and stocking standard (Haigh 1931; Cowlin 1932; Wellner 1940; Lynch and Schumacher 1941; Candy 1951; Bella 1976; Bella and De Franceschi 1978), ensuring the accuracy of stocking estimates (Trousdell 1954; Ghent 1963, 1969; Payandeh 1970; MacLeod 1977; Kaltenberg 1978; MacLeod and Chaudry 1979; Fox *et al.* 1984), finding the relationship between stocking and number of trees (Gill, 1950; Grant 1951), assessing guidelines for defining acceptable reproduction (Robinson 1975; Ferguson 1984). In the meantime, another important problem, that of relating stocking of regeneration to yield at maturity was left almost untouched. A thorough search of the literature yielded only two papers dealing with this matter. Braathe (1976) studied the development of semimature naturally regenerated Norway spruce (*Picea abies* (L.) Karst.)stands in Norway and tried to relate their yield to their density at the time of regeneration, density being measured by the number of occupied 4-m^2 quadrats. In Washington State, U.S.A., Stabler (1949) projected the development of young Douglas-fir (*Pseudotsusga menziesii* (Mirb.) Franco) stands of varying density for a period of 15 years. Despite the interesting results obtained with these two studies, assessment of regeneration continues to rely on stocking standards that relate yield to density in very broad terms only.

The purpose of this presentation is to try and answer the following question: what is the relationship between stocking of regeneration and yield of the mature stand that will develop from it? To do this, I will use data gathered in naturally regenerated jack pine and black spruce stands.

METHODS

Basically two methods can be used to relate yield at maturity to stocking of regeneration. In the first one, regenerating stands are sampled for stocking and followed until yield can be measured directly. This implies a long waiting period before results are available, currently 40 years or more for jack pine and black spruce. The second method relies on direct measurement of yield in mature stands, together with an estimation of stocking at the time the stand became established. This was the method used in the present case.

Semi-mature stands of each species, covering the largest possible range of density and site, were selected throughout their geographical range in Quebec. Only pure stands, that is having less than 25% of basal area in other species, were retained. In each stand, an area of 0.2 ha (40 x 50 m) was delineated, in which the position of each stem, living or dead was mapped. However, stems more than 15 years younger than the main stand were excluded. Age was counted at breast height in cases of doubt.

The diameter of each tree was measured to the nearest millimeter at 1.30 m from the ground and its status, whether living or dead, was noted. Total height and age of a representative sample, encompassing the range of diameters, were also determined. Trees were aged at breast height for convenience; age at ground level was occasionally checked. Total age was estimated by adding a variable number of years, depending on site class as suggested by Hahn and Carmean (1982).

Stocking of each stand, for various quadrat sizes, was computed from the information on the position of each tree, and this was considered as the stocking at time of stand establishment. The effect on stocking of excluding stems that were below a specific diameter was examined and found to be negligible up to a dbh of 7 cm. Thus, the occasional inclusion of younger stems, which were also the smallest, should not have had much effect.

Yield was estimated by total and merchantable volume (9-cm minimum diameter).

Table 1 Stand Characteristics

Parameters	Jack pine (N = 35)			Black spruce (N = 28)		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Total volume (m^3/ha)	49	132	229	135	156	227
Merch. volume (m^3/ha)	20	112	222	11	123	207
Site index (m/50 years)	5.9	13.7	17.3	7.0	13.5	19.0
Stocking (%)						
4-m^2 quadrats	11	48	97	38	63	94
8-m^2 quadrats	22	67	100	58	80	99
Age (years)	42	51	67	42	64	83

Height-dbh curves were calculated and used to prepare local volume tables from published regional volume tables based on diameter and height (Tremblay 1966; Perron 1980). Site index was obtained from age and height data of dominant and codominant trees, using the formulated site index curves of Payandeh (1977).

Table 1 describes the data that were obtained by sampling 35 jack pine and 28 black spruce stands. They were used for relating yield (as measured by volume) to stocking at time of establishment, site index and age, through non linear regression analysis, using the Gauss-Newton method for iterations. Theoretical considerations on the behavior of the independent variables, and examination of the data led to choosing the following model:

$$V = \beta_1 I^{\beta_2} (1 - e^{\beta_3 S}) (1 - e^{\beta_4 A})$$

where V = Total or merchantable volume (m^3/ha)
I = Site index (m at 50 years)
S = Stocking at establishment (%)
A = Stand age (years)

β_1 .. β_4 = Parameters to be estimated.

A linear regression of the form:

$$V = \beta_1 + \beta_2 I + \beta_3 S + \beta_4 A$$

was also calculated for comparison with non-linear regression results.

RESULTS

Parameters of the equations for jack pine are presented in Table 2 and the results are illustrated in Figures 1 and 2. It can be seen from the approximate coefficients of determination (or pseudo R^2) that the model is successful in describing how yield, as measured by volume, changes with site, stocking, and age. Similar results were obtained with multiple linear regression, but the non-linear equations have the added advantages of going through the origin and having a consistent behavior outside the range of data.

It can be seen from Figure 2 that yield increases rapidly at first with an increase in stocking, but begins to level off at a stocking of approximately 40% as measured with 4-m^2 quadrats. The increase in yield is minimal at stocking over 60%. When stocking is measured with 8-m^2 quadrats, yield increase is maintained up to about 70% stocking, then levels off. Similar results were obtained when merchantable volume was used to estimate yield.

Fig. 1 Effect of stocking ($4m^2$) on yield at 50 years in jack pine.

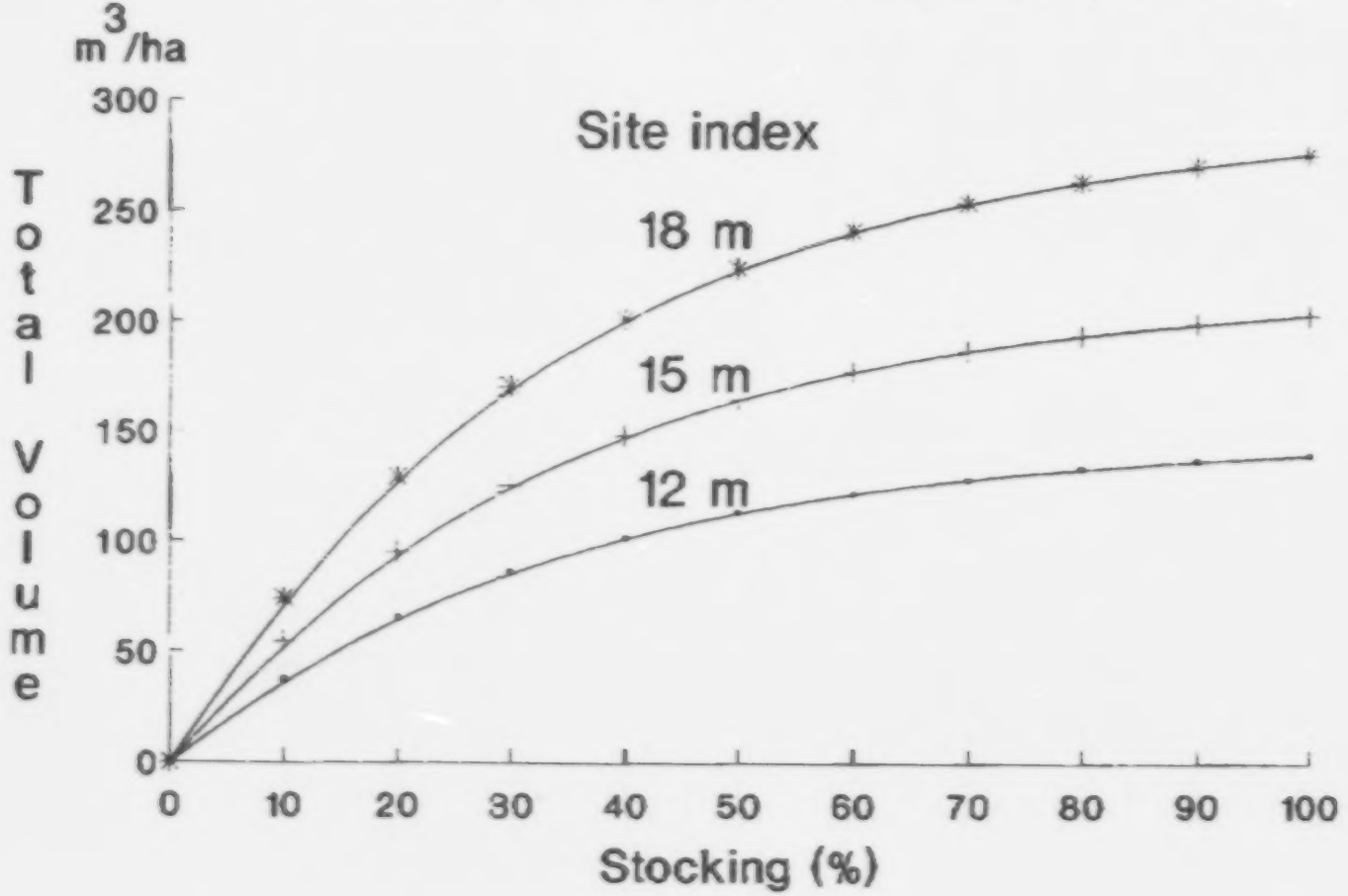


Fig. 2. Effect of stocking ($8m^2$) on yield at 50 years in jack pine.

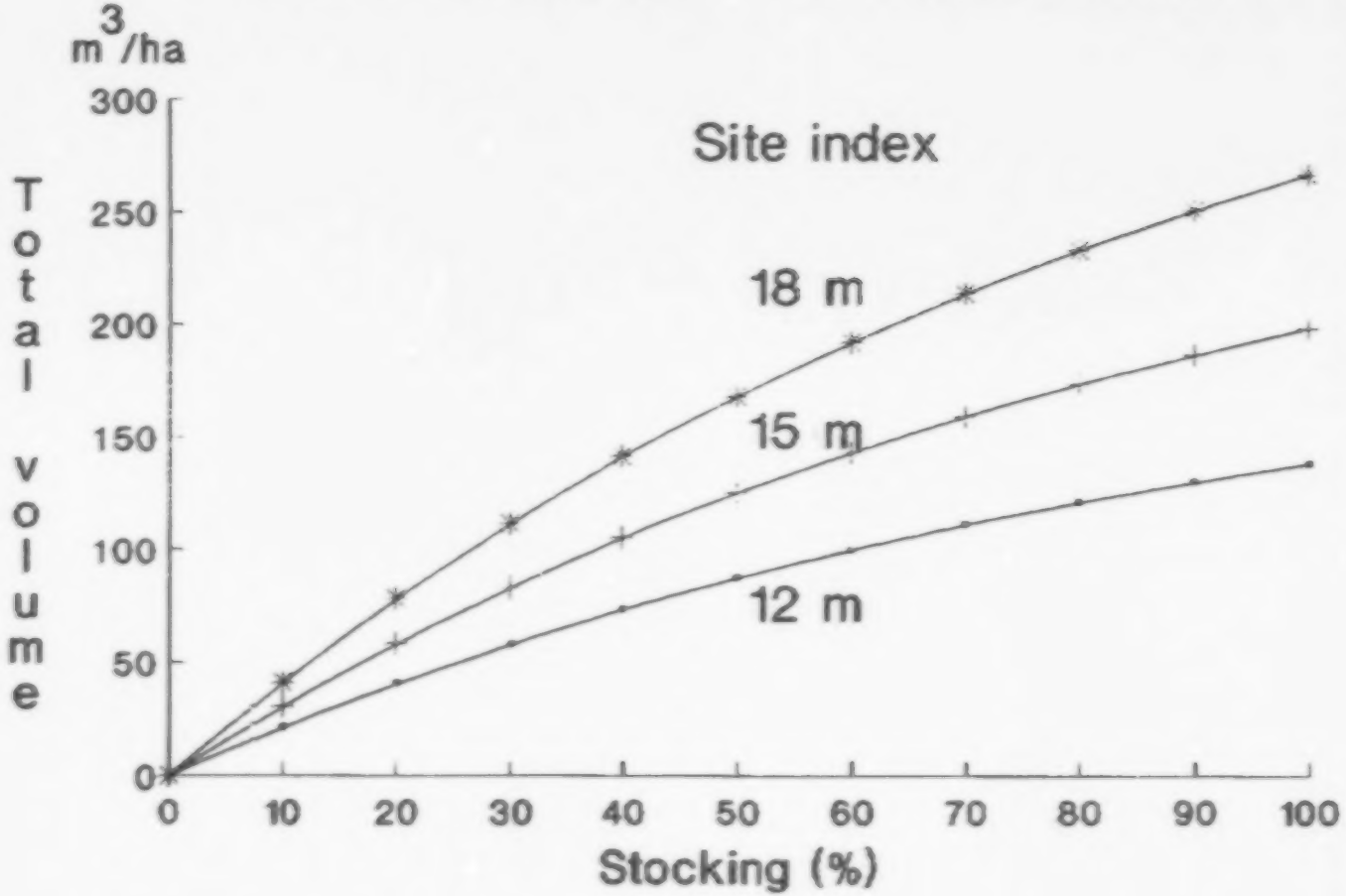


Table 2 Parameters of the equation for jack pine

Parameter	Total volume		Merchantable volume	
	4-m^2 quadrats	8-m^2 quadrats	4-m^2 quadrats	8-m^2 quadrats
β1	2.9016	4.6232	0.6650	0.8135
β2	1.6816	1.6204	2.3187	2.2748
β3	-0.0291	-0.0107	-0.0393	-0.0171
β4	-0.0304	-0.0336	-0.0127	-0.0145
Pseudo R^2	0.928	0.935	0.905	0.908

The non-linear approach failed to give satisfactory results with black spruce. However, the following multiple linear regression was obtained using 4-m^2 quadrats:

$$VT = -295. + 18.577I + 2.959A + 0.220S \quad R^2 = 0.746$$

where VT is total volume and the other variables are as previously defined. The value of β3 (0.220 is not significantly different from zero ($p = 0.63$), which means that yield is independent of stocking within the range of stocking sampled.

DISCUSSION

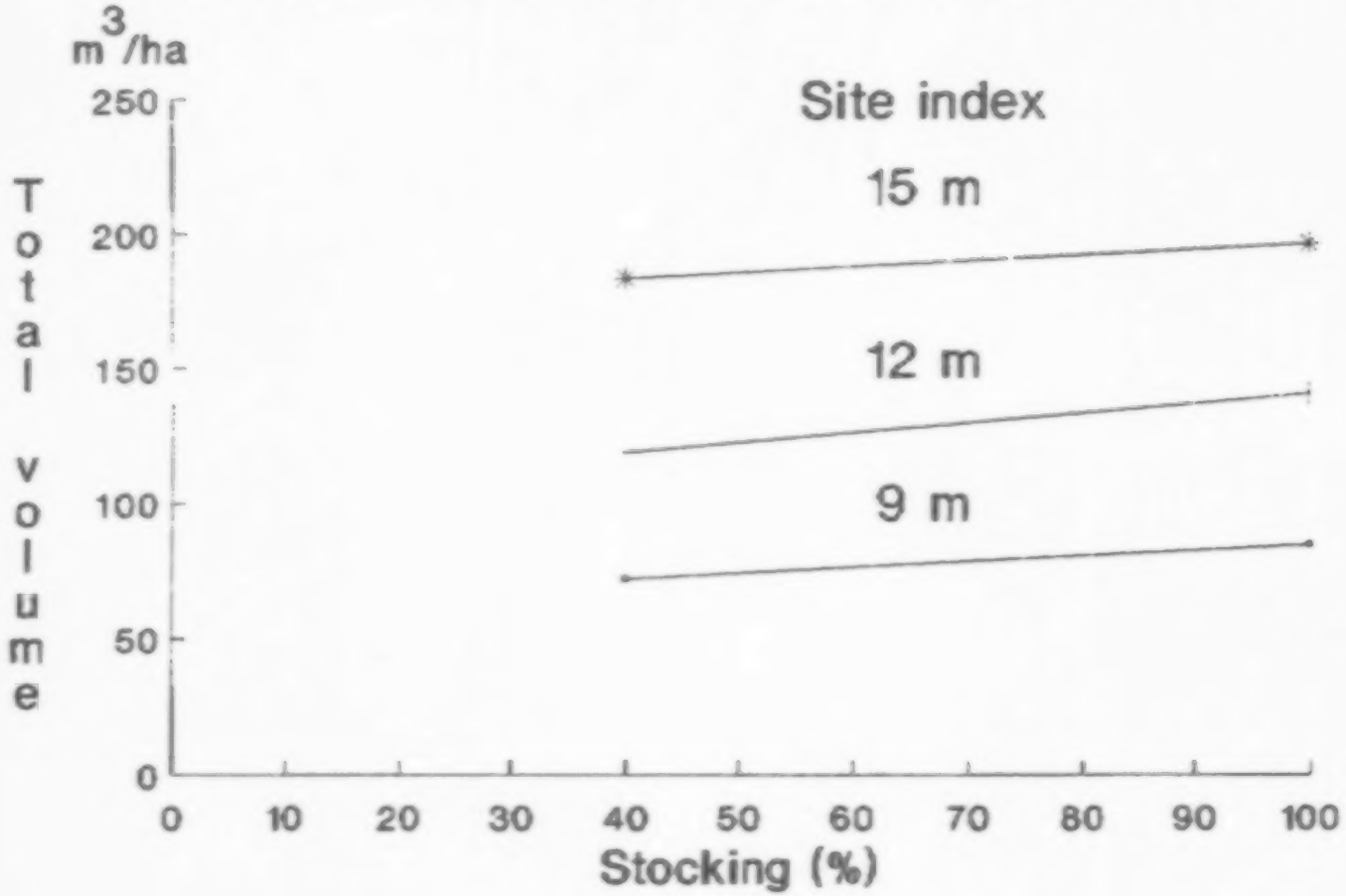
The jack pine data covered a range of density from open to very dense stands. A good fit was obtained with the model used and results corresponded to what one would intuitively expect. At low stocking, yield increased rapidly with an increase in stocking and then tended to level off. However, relatively good yields were obtained at stocking levels that have usually been considered as failures (Candy 1951; Paquet 1984) and rates of increase slowed down rapidly thereafter.

The almost linear rate of increase in yield was maintained over a larger range of stocking when 8-m^2 quadrats were used as units of stocking measurement. This suggests that a 8-m^2 quadrat is more closely related to the area needed for a tree to reach maturity than is a 4-m^2 quadrat. As stated by Stein (1983), quadrat size must have a logical relation to the area needed to support a tree to maturity. It is interesting to note that a quadrat size of 10 m^2 was suggested for lodgepole pine (*Pinus contorta* Dougl. var. *Latifolia* Engelm.) and white spruce (*Picea glauca* (Moench.) Voss) in Alberta, based on considerations of the number of open-grown trees to give a 100% crown cover (Bella and De Franceschi 1978).

Black spruce results were less reliable, probably because sampling was inadequate. Few data were available at stocking below 50% (measured with 4-m^2 quadrats), where the influence of stocking on yield should be strong. This lack of effect of stocking on yield, within the range of stocking sampled for black spruce, is consistent with the results for jack pine, but more sampling of low density stands will be needed to confirm this trend. Pure, low-density jack pine stands were easily found, but it was not so with black spruce. It is possible that the available growing space of black spruce stands tends to be occupied by other tree species, giving rise to mixed stands. Pure stands only were sampled in order to avoid the problem of interspecific competition which would have been confounded with that of stocking.

The reliability of these results ultimately rests on whether or not initial stocking can be accurately estimated in stands approaching rotation age. This cannot be measured directly but can be inferred from information on how stocking changes with time. Except for the

Fig. 3. Effect of stocking (4 m^2) on yield at 65 years in black spruce.



very first years when seedling mortality can be substantial and very erratic (Riley 1975; Sims 1970), stocking of free-to-grow seedlings will tend to remain the same (Peng-Chea and Paquet 1984) or increase slightly (Peng-Chea and Paquet 1981; Riley 1980; Smith 1984) for the first 10 years after stand establishment. Data presented by Lyon and Thomson (1979) and Sleep (1975) even suggest that this trend can be extended up to about 25 years. Whether it continues further can be inferred from the pattern of density-dependent, or "regular" mortality (Rennolds and Peace 1986). In Ontario, white spruce and red pine (*Pinus resinosa* Ait.) plantations spaced approximately 2 x 2 m (100% stocking with 4-m^2 quadrats) experienced negligible mortality, at least up to 30 years from planting (Stiell and Berry 1973a,b), as did Scots pine (*Pinus sylvestris* L.) plantations in England (Rennolds and Peace 1986). Even in an overstocked jack pine stand (about 15 000 stems/ha), mortality was not evident until age 20 (Yarranton and Yarranton 1975). In naturally regenerated stands, mortality does not necessarily mean a reduction in stocking, as stocked quadrats are often occupied by more than one tree. Trees that die at an older age should be more easily found several years later, because of their larger dimensions, so that their contribution to initial stocking is more easily estimated. Moreover, mortality will tend to be clumped and occur in denser patches (Kenkel 1988), so that its effect on stocking will be minimized. This hypothesis was tested with both jack pine and black spruce data. It was found that stocking decreased only slightly (usually less than 3%) when trees 5 cm dbh or less, which were almost all dead, were excluded from the database. It can thus be assumed that initial stocking was reasonably well estimated.

It could also be argued that the stocking actually measured was in fact larger than initial stocking, because an increase often occurs after stand establishment, as previously discussed. In the stands sampled, trees that became established after a delay of a few years did not contribute much to total yield. Jack pine and black spruce establishment is usually complete within a few years after fire (Sirois and Payette 1989; St-Pierre 1990). Moreover, an extensive study of 40- to 60-year-old black spruce stands originating from clearcutting also showed that they had originated almost exclusively from advance growth (Doucet 1990). In any case, if stocking did in fact increase, the estimates provided by the equations will err on the conservative side, predicting somewhat lower yields for a given stocking level.

USING THE RESULTS

These results can be used to estimate the yield that can be obtained at rotation age from a given stocking level of the regenerating stand. Instead of relying on a single stocking standard for success, the forest manager can evaluate what will be the yield in each case, and how will it affect the future allowable cut. The effect on yield of a given increase in stocking can also be evaluated. If the value of this extra wood, and the cost of the treatment needed to get it, are known, a sound decision can be made on the relevance of applying the treatment. Classifying sites in order of treatment priority is also made easier.

Even though a range of age was sampled, using these results to derive growth and yield tables is not recommended. Age was restricted to the smallest range possible, close to rotation age, and was included in the equations only because it was impossible to get enough samples when restricting sampling to stands of exactly the same age.

Using these equations requires an estimate of site productivity. Site index was selected because it is a quantitative variable and is recognized as one of the best methods for measuring site quality (Tesch 1981). However, it cannot be estimated directly in stands that are in the regenerating phase. Indirect methods of es-

timation that can be used include the height/age relationship of the previous stand (Evert 1975), or the relationship between site index and characteristics such as soil and topography (Schmidt and Carmean 1988).

This method should also be restricted to free-to-grow regeneration. When competition from unwanted vegetation is severe, the problem cannot be solved by an increase in stocking, or at least the outcome is unpredictable. The same could be said when catastrophic events such as heavy insect or disease infestations occur. In such instances, high stocking cannot guarantee that future yield will be adequate.

Whether these results can be used for predicting future yields of plantations from percent survival in the establishment period is open to question. Unlike plantations, naturally regenerated stands often have more than one seedling per stocked quadrat, especially at higher stocking, so that death of a few individuals does not necessarily mean a decrease in stocking. Consequently, using the equations of the present study in plantations could lead to unreliable estimates.

Considerations other than yield also play a role in setting a goal for stocking level. For example, it was found that a large proportion of the stems tended to develop large branches when stocking (4-m^2 quadrats) fell below 40%. However, this was not studied further.

CONCLUSION

The method used for relating initial stocking of regeneration to yield at maturity proved reasonably successful for jack pine. The forest manager is thus in a position to estimate future yields that will result from any level of initial stocking, instead of relying on a standard that tells nothing about what can be expected when it is not met. Calculating future allowable cut, or ranking sites according to priority of treatment is also made easier. Black spruce results were less satisfactory, but they followed the same trend as those of jack pine. This problem should be corrected when samples covering a larger range of stocking are available.

ACKNOWLEDGEMENTS

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HERBICIDE TECHNOLOGY FOR SECURING NATURALLY REGENERATING STANDS

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HISTORICAL EVOLVEMENT

The importance of managing vegetation to reduce competition to desirable conifer crops, the timing of treatments, and interaction of site quality are described in early literature (Fernow *et al.* 1912; Fisher 1918). In northeastern North America, the first helicopter application of herbicide (2,4-D) for silvicultural improvement of woodlots was accomplished in 1947.[a] Interest in using the technology for release of conifers increased into the early 1950s (Arend and Coulter 1955; Arend 1959). McConkey (1958) carried out studies on the Massabesic Experimental Forest, Maine, that documented the benefits of aerial application of 2.4,5-T to release young pine regeneration. These early successes were achieved by releasing natural regeneration and preceded the relatively recent interest in release of plantations. In 1963, several papers were published in the Proceedings of the Northeastern Weed Control Conference (Vol. 17, now the Northeastern Weed Science Society) that pertained to herbicide technology as a silvicultural tool. Included in that program were reports of aerial applications in Maine (Dineen 1963), New Hampshire (Sargent 1963), and Vermont (Butler *et al.* 1963).

Use of the phenoxy herbicides, principally 2,4-D and 2,4,5-T, progressed into the 1970s and the silvicultural effectiveness of such treatments became well recognized. From the mid-1970s into the 1980s, new chemistry, such as glyphosate and triclopyr, offered improved levels of efficacy and silvicultural prescription options (Sutton 1985, McCormack 1985, Malik and VandenBorn 1987). In 1987, Walstad and Kuch brought together a comprehensive volume on managing vegetation for production of conifer crops. This included discussion of the Northeast (Newton *et al.* 1987).

CURRENT TECHNOLOGY

For securing natural regeneration, the most common practice is aerial application as solutions or emulsions in water. Some ground application is carried out, but suffers from several disadvantages:

1. More herbicide is required to achieve a level of efficacy equivalent to an aerial application on the same site,

2. Much higher volumes of total spray solution are required (*e.g.*, 30 to 40 L/ha for aerial, 400 to 600 L/ha for ground),

3. Vegetation disturbed by ground equipment is less susceptible to treatment and desirable regeneration can be damaged,

4. It is difficult, if not impossible, to achieve accurate calibration and uniform coverage,

5. Productivity is relatively low compared to aerial application and limits land areas which can be treated operationally,

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[a] Personal communication, Robert J. Broadley, Chief Pilot, Plymouth Copters, Ltd., Plymouth, MA.

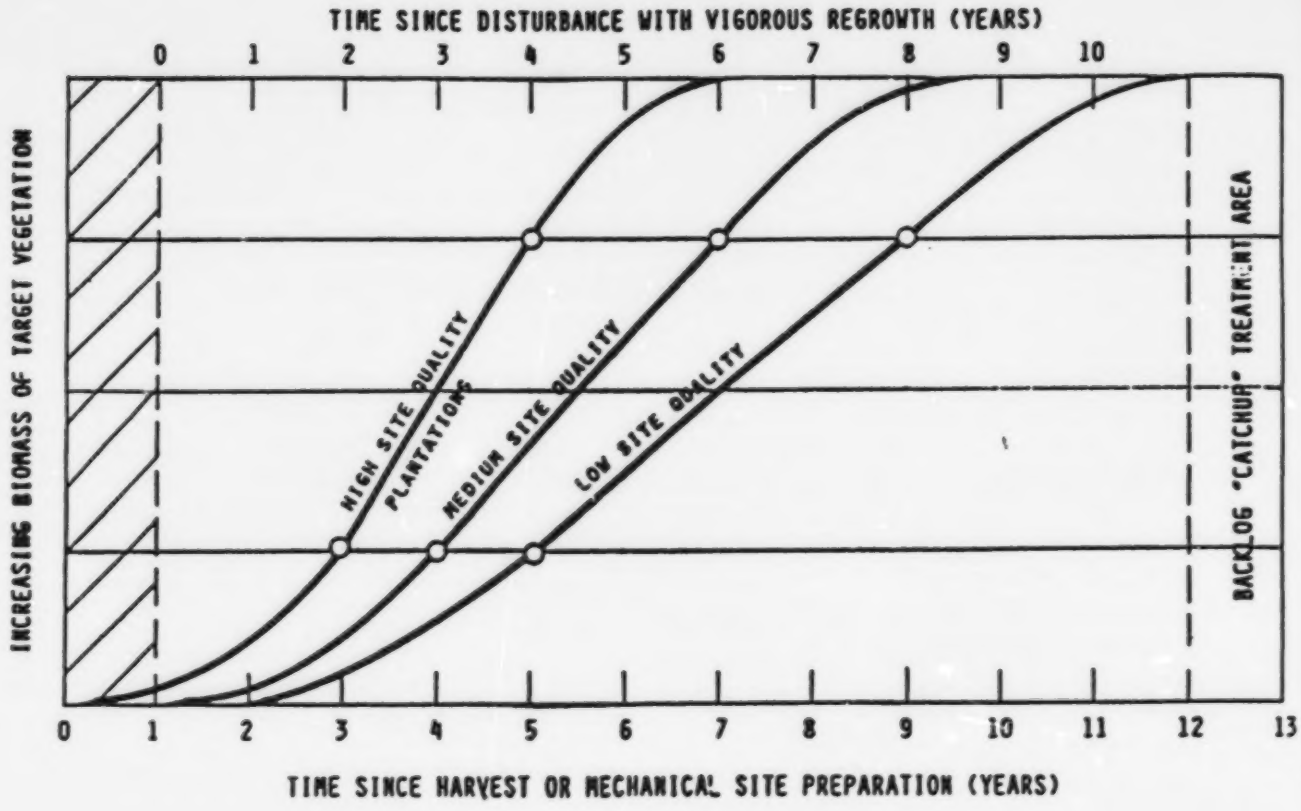
TIME SINCE DISTURBANCE WITH VIGOROUS REGROWTH (YEARS)
0 1 2 3 4 5 6 7 8 9 10
INCREASING BIOMASS OF TARGET VEGETATION
HIGH SITE QUALITY PLANTATIONS
MEDIUM SITE QUALITY
LOW SITE QUALITY
BACKLOG "CATCHUP" TREATMENT AREA
0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME SINCE HARVEST OR MECHANICAL SITE PREPARATION (YEARS)

Figure 1 Different rates of development of competing vegetation biomass for three different levels of site quality. The development is shown over time following disturbance of the site. This relationship applies to plantations as well as natural stands. The small circles on the curves mark the period of time where release treatment would be a critical need. These curves also illustrate the most likely time period for treatment from a management planning perspective.

6. There is a higher risk of worker exposure to chemicals, and

7. There are higher costs of treatment per unit of land area.

Where ground application is absolutely essential, new technologies, such as the Radiarc®[b] Sprayer provide a means for improved uniformity of coverage and calibration over the delivery systems used in the past, such as boomless nozzles. Natural regeneration areas are usually rough and irregular, making consistent, calibrated movement of ground equipment extremely difficult and often dangerous.

Aerial application, on the other hand, provides a safe effective herbicide delivery with a secure spray pattern. For example, silvicultural effectiveness can be achieved with 3 to 6 L of glyphosate in total spray volumes as low as 20 L/ha. To achieve efficacy with such low volume aerial applications, it is important to ensure that spray patterns are composed to proper droplet sizes (Schaertl *et al.* 1988). Equipment developments, improved batching and loading procedures, and more intensive management of aircraft operations now enable crews of three to ten people to effectively treat 400 to 750 ha in a day, weather permitting. Such procedures make large operational programs feasible with individual jurisdic-

[b]The Radiarc® Sprayer. Waldrum Specialties, Inc., Doylestown, PA 18901

tions treating 20 000 to 50 000 ha in a late summer-autumn spray season.

In addition to considering the herbicides and delivery systems, an important aspect of sound silvicultural use of the technology is timing. Vegetation dynamics, especially competing vegetation, vary with site quality. The more productive a site, the more rapid is the development of the undesirable vegetation (Figure 1). Using the generalized curves of Figure 1 for reference, one can see, for example, that if vegetation is to be treated between 25 and 75 percent of its full development, high quality sites should be treated between years 3 and 5 following disturbance (*i.e.*, harvesting). In contrast, low quality sites might be successfully treated between years 5 and 9. However, a site reaches a condition where best possible returns from maintaining crop tree growth momentum and desirable species treatment can provide benefits (on these curves, it is somewhere between years 6 and 12 following disturbance), but they do not equal the maximum benefits possible from earlier, timely silvicultural prerelease that enables crop trees to maintain their peak growth momentum.

Challenges exist to the technology. When due process allows science and facts to be considered, it has been shown that the technology is safe, sound, and effective (Nunn 1983). And, where toxicological risk is a major concern, thorough reports have shown such concerns are unfounded (Newton and Dost 1984; Shipp *et al.* 1986). Since glyphosate is the most commonly used active ingredient in the Northeast, it is appropriate to focus on extensive documentation of its interactions with biological systems and the forest ecosystem. Of particular value is the monograph edited by Grossbard and Atkinson (1985). Rueppel *et al.* (1977) continues to be a useful reference on fate of glyphosate in soil and water. Fate of glyphosate in an Oregon forest ecosystem is described in detail by Newton *et al.* (1984) and the recently published Carnation Creek Proceedings (Reynolds 1989) provides papers on a wide array of glyphosate interactions on a watershed study site.

Recently, many concerns have been expressed over possible detrimental effects of herbicide use on forest wildlife habitat and the need for study of these effects. A report by Newton *et al.* (1989) quantifies what has been the general observation of conditions following conifer release in Maine; such practices improve conditions for resident browsers. On a broader scope, Miller *et al.* (1990) conducted a literature review and have abstracted 293 references on interactions of herbicides and wildlife habitat.

SILVICULTURAL EFFECTIVENESS

Long-term documentation of effectiveness of herbicide treatments on securing regeneration are limited. This is due, in part, to the relatively short-term nature of pressure-to-publish and mobility of personnel in the forestry research community. However, the principal reason for the dearth of documentation is the visually dramatic positive responses to treatments that have satisfied foresters to the point that photographs and emotional exclamations have precluded collection of data to document the results for the hearing rooms and executive meetings of present times.

Benefits fall into two categories:

1. Species composition and improved stocking of crop trees, and

2. Positive growth responses of crop trees.

In the first case, developing regeneration that might deteriorate and possibly be lost, can be developed into adequately stocked stands deserving of further management. To illustrate, Table 1 shows comparative crop tree stockings following a variety of herbicide treatments.

Table 1 Crop tree stocking per hectare by treatment 9 years after herbicide release (16 years after harvest). Bald Mountain Twp., Maine.

Herbicide	Rate (kg a.e./ha)	Crop Trees/ha[a]	Equivalent Stocking (%)
2,4-5-T	2.2	1345	80
	3.3	1392	83
2,4-D + 2,4,5,-T	1.1 + 1.1	1561	93
	2.2 + 2.2	1417	84
Glyphosate	1.65	1488	88
	3.3	1200	71
Triclopyr	2.2	1392	83
	4.4	1392	83
Triclopyr + 2,4-D	2.2 + 2.2	1392	83
Control	-	432	26

[a]Crop trees were spruce or fir, on 3.64-m radius plots, that were 1.34 cm or taller in height, conforming approximately to 2.44 x 2.44 m spacing, and were free to grow (*i.e.*, at least codominants in an approximate 2.44 x 2.44 m (8 x 8 ft) spacing. By this method the maximum stocking attainable was 1680 trees per hectare (680 trees/acre). (Adapted from a manuscript by Newton, Cole, McCormack, and White currently under review.)

Another aspect of crop tree stocking manipulation is the use of herbicdes to reduce overstocking. Tree injection, the practice of placing metered amounts of herbicide directly into specific target stems, has been carried out successfully for many years. It is a labor intensive procedure that is very specific in removing individual stems from a developing stand. Over the past eight years, an aerial technique for mechanical precommercial thinning of large areas of natural regeneration has been developed (McCormack and Lautenschlager 1989). Helicopters can deliver predetermined band patterns across target areas that result in removal of strips of all vegetation leaving narrow residual strips of potential crop trees.

A recent review of a wide range of studies and file reports by this writer[c] considered growth responses of natural regeneration and plantations composed of conifer species typical of the Ontario area of the undertaking (*e.g.*, red pine, jack pine, black spruce, white spruce, balsam fir). Relative growth/volume increases were consistently positive and ranged from 34 to 1246 percent improvement over comparison trees or stands.

To specifically illustrate response patterns, Figure 2 displays average spruce and fir crop tree volumes for the same stands shown in Table 1. The pattern relative to increasing levels of competing vegetation was consistent and, when these individual crop tree volumes are combined with the improvements in stocking, the volumes per land area unit are greatly improved over those of untreated controls.

To illustrate portions of a hypothetical large block of land allocated to timber harvest under four different levels of intensity of silviculture, Seymour and McCormack (1989) formulated yield assumptions shown in Figure 3. This illustrates the potential benefit of a timely herbicide treatment where adequate stocking

[c]OFIA/OLMA Statement of Evidence, Class Environmental Assessment (No. NR-AA-03) of an undertaking by the Ministry of Natural Resources for the activity of timber management on Crown lands in Ontario.

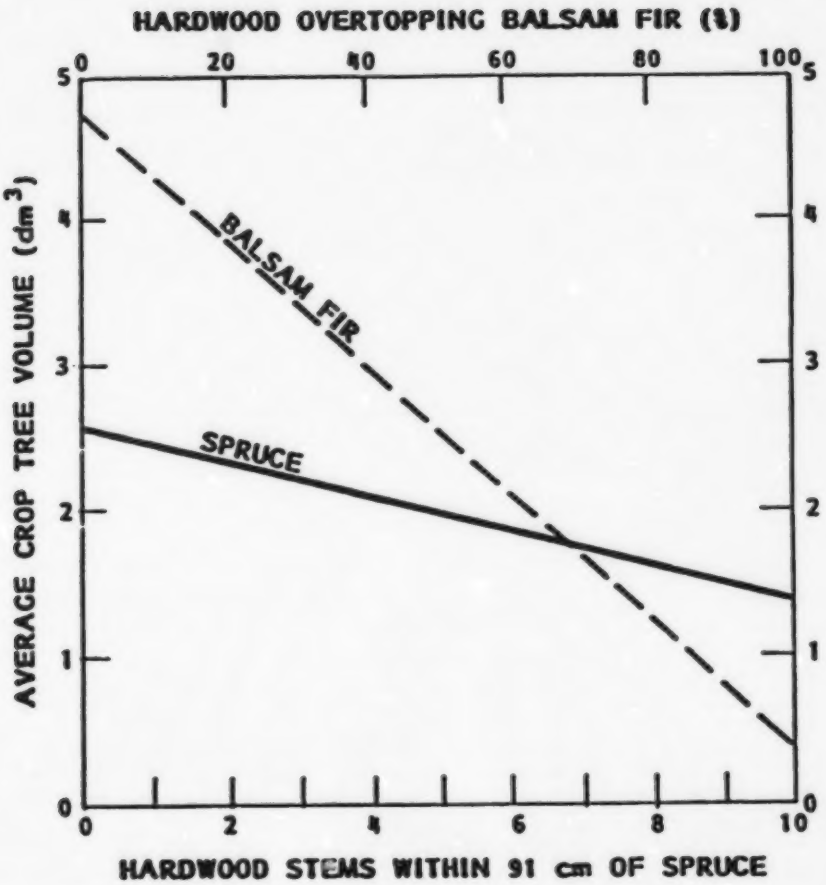
HARDWOOD OVERTOPPING BALSAM FIR (%)
0
20
40
60
80
100
AVERAGE CROP TREE VOLUME (dm^3)
5
4
3
2
1
0
BALSAM FIR
SPRUCE
0
2
4
6
8
10
HARDWOOD STEMS WITHIN 91 cm OF SPRUCE

Figure 2

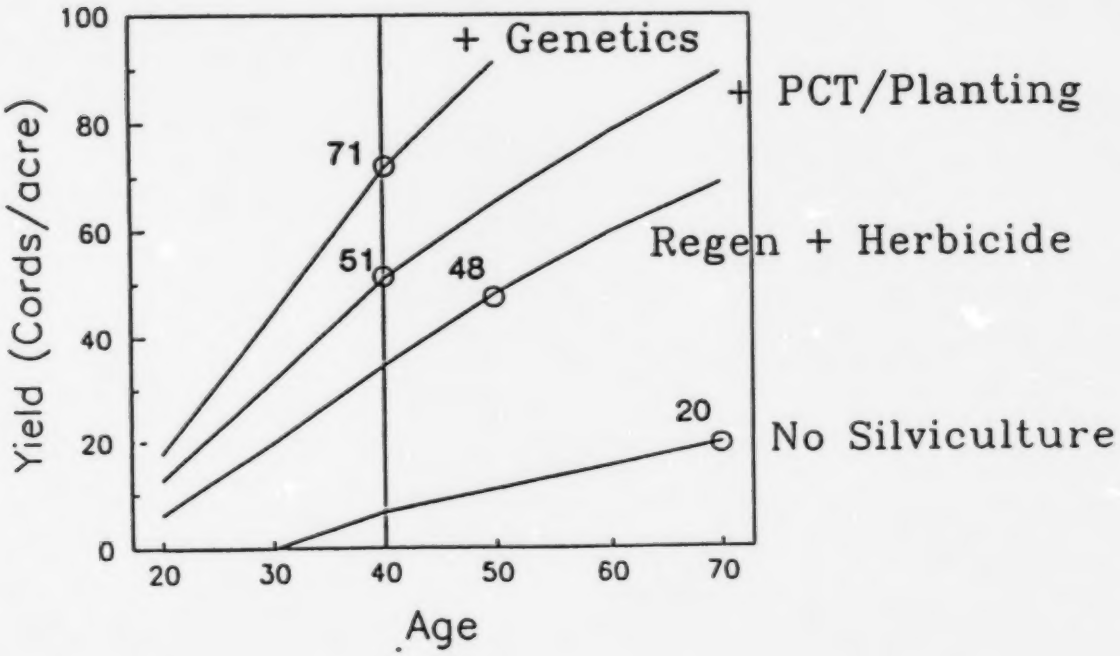

Figure 3 To illustrate the potential of high-yield silviculture, four scenarios were used, tabulated by Greenwood *et al.* (1988). The "NO SILVICULTURE" yield curve was derived from unpublished data obtained in the most recent USDA Forest Service resurvey of Maine (Powell and Dickson 1984). It represents historical, empirical yields of spruce and fir only (no other species) from six million acres of spruce-fir forest type.

The four curves represent four scenarios for spruce-fir stands assumed to be growing on site-index 60 land (average height of dominant trees to reach 60 feet in 50 years) which is considered above average height for the spruce-fir region. The curves represent projected yields (cords of merchantable wood/acre) over stand age (years). The vertical line at age 40 represents a desirable rotation length with high intensity silviculture.

The bottom curve represents natural spruce-fir stand development with no silviculture whatsoever. At age 50, it would yield about 10 cords/acre with an anticipated yield of 20 cords at age 70. The three higher curves represent incremental (cumulative) additions of silvicultural treatments which illustrate the prerequisite nature of herbicide technology to carrying out further silvicultural improvements.

The term "Regen" indicates an improvement in stocking of natural regeneration to 80%. The term "+ Herbicide" indicates a timely herbicide treatment to maintain that regeneration in a free-to-grow condition. With these improvements, a yield of 48 cords/acre is expected at age 50.

In the next higher curve the term "+ PCT/Planting" indicates increased stocking to 90% and crop tree spacing controlled by either precommercial thinning (PCT) of fully stocked natural stands or by planting trees for plantation production. With this scenario, 51 cords/acre is expected at age 40. To attain the highest yielding scenario (:"+ Genetics" with 71 cords/acre at age 40), yields of the planting scenario were increased by 40% to represent results of an intensive clonal tree-improvement program.

is present. Further silvicultural treatment follows, and is dependent on, that timely (and effective) silvicultural release.

Thus, these documents show that herbicide technology to benefit natural regeneration is a long-established, well documented, safe practice. With properly formulated prescriptions, effective operational treatments result in improved stocking and growth rates of managed forest stands.

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EARLY RESPONSE OF BALSAM FIR (*ABIES BALSAMEA* (L.) MILL.) TO PRECOMMERCIAL THINNING IN THE CONTEXT OF SITE QUALITY

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ABSTRACT

Twenty-nine 0.02-ha plots were established in precommercially thinned stands growing on soils ranging from poorly to well drained. Detailed stem analysis was used to evaluate the response of balsam fir trees to thinning. Two-year pre- and postthinning volume increments were determined for 218 dominant and codominant sample trees. Postthinning volume increment was expressed as a function of prethinning volume increment and competition index (the ratio of crop tree basal area: basal area of competing crop trees), which were selected as predictor variables by stepwise regression. Subsequently, a model to predict postthinning volume increment was developed for each drainage class.

Regression with dummy variables indicated that the model predicting postthinning volume increment could be simplified by (i) using a single coefficient (instead of four) for competition index; (ii) combining moderately well and well drained soils (better drained); and (iii) combining poorly and somewhat poorly drained soils (imperfectly drained). Simplification of the original model clarified growth response to thinning among the drainage classes. Volume increment for individual trees on the better drained soils was 1.6 times greater than that before thinning. In contrast, imperfectly drained soils supported trees with volume increments only 1.3 times that of prethinning volume increment. Site quality has a measureable effect on the tree growth response to silvicultural treatment.

INTRODUCTION

During the past 10 years, there has been a tremendous increase in the intensity of forest management in Maine as well as in the Canadian provinces. Herbicide application and precommercial thinning (spacing) have been used to insure vigorous development and growth of conifers. In an effort to insure maximum return on silvicultural investments, more attention is being paid to evaluation of site quality and its relationship to stand growth.

The Cooperative Forestry Research Unit (CFRU) at the University of Maine initiated a research project to develop a productivity oriented site classification system for spruce and fir in the state of Maine (Briggs 1988). A literature review revealed that significant effort has been devoted to site evaluation for spruce and fir in Maine since the mid 1950s. With the exception of McLintock (1957), who worked in mixed hardwood and spruce stands, much of the work focused on soil-site relationships for mature, fully-stocked, even-aged spruce-fir stands (Young 1954; Schillinger 1971; Allen 1978; Haag 1980; Schiltz and Grisi 1980; Williams *et al.* 1990). These soil-site studies pointed out the overwhelming influence of drainage class on stand growth and development. Spruce and fir growing on bet-

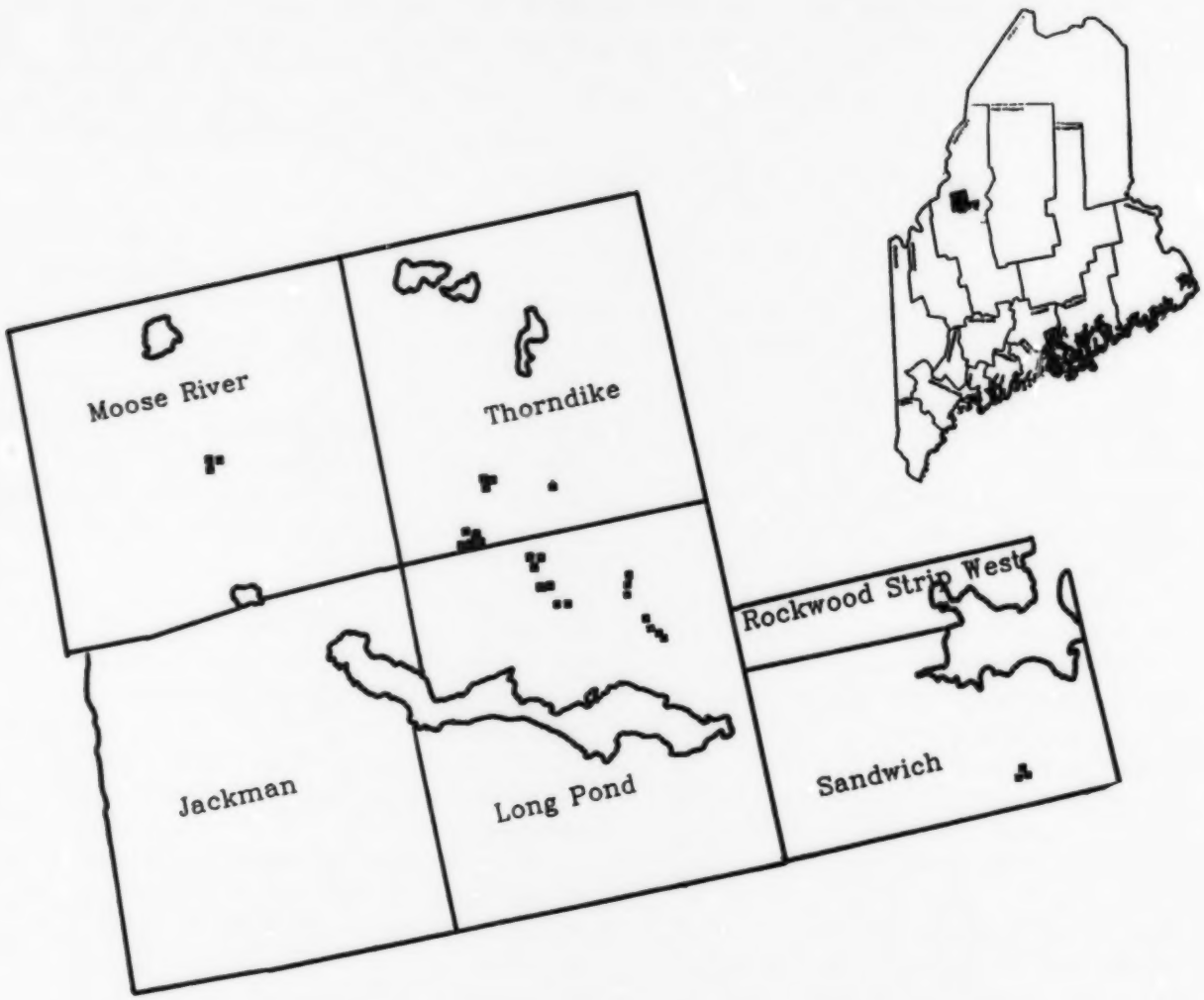

Figure 1 Map of the central portion of Somerset County, ME, illustrating locations of the plots established in precommercially thinned stands during the 1989 field season.

ter drained soils (well and moderately well drained) generally exhibited greater rates of height growth and expressed dominance at earlier ages relative to those on imperfectly drained (poorly and somewhat poorly drained) soils. Although differences in total volume and total biomass between the better drained and imperfectly drained soils were not apparent until after 60 years of age, volume and biomass were distributed over a smaller number of stems on the better drained soils. As a result, better drained soils were associated with greater merchantable volume (Schiltz and Grisi 1980; Williams *et al.* 1990).

Initially, the CFRU site evaluation project focused on expanding the existing soil-site data base through the establishment of additional plots in even-aged, fully-stocked, mature spruce-fir stands. Location of plots across the range of site conditions is a prerequisite for successful soil-site studies. After two field seasons, it became apparent that the opportunity for locating a suitable number of such stands on better drained soils was limited; an alternative approach was required.

During the summer of 1989, emphasis was shifted to studying soil-site relations with

young trees growing in precommercially thinned (PCT) stands. There were several reasons for this shift in emphasis. First, tree growth following removal of competition by PCT theoretically reflects site quality. Second, PCT stands are currently distributed over a wide range of site conditions. Third, PCT has become a popular silvicultural treatment and more information on growth and development of young stands is needed.

The objective of this study is to determine if the early growth response of balsam fir following release from competition by PCT is influenced by soil drainage class. Drainage class is an important component of site quality, influencing effective moisture supply, soil aeration, and soil temperature. Impacts of drainage class on the growth and development of unmanaged stands, previously described, have been well documented. Very little work has been done in young, intensively managed stands.

METHODS

Field

The study area (Figure 1) is located in the central portion of Somerset County, Maine (approximatly N 45°30', W 70°00'), in the Central Highlands physiographic province (Denny 1982). Elevations of individual study sites, determined from USGS topographic maps, ranged from 365 to 460 m. Meteorological data for 1988 from Brassua Dam, the weather station in closest proximity to the study area, provided some indication of the climate. Mean annual temperature was 3.7°C, with a mean monthly high of 19.3°C in July and a mean monthly low of -12.4°C in January. Total precipitation, which averaged 887 mm (-107 mm departure from normal), was evenly distributed throughout the year (N.O.A.A. 1988).

During July and August of 1989, twenty-nine 0.02-ha circular plots were established in fully stocked portions of PCT stands (Figure 1). Plots were established so that soil conditions were uniform within the plot boundary. Twenty-six plots were located in stands that were thinned in 1985 or 1986; three were located in a stand thinned in 1981. The majority of plots (23) were located in stands that had been treated with herbicide (Garlon or Glyphosate) for control of herbaceous and hardwood competition 2 to 7 years prior to thinning. The six plots in stands near large streams never received herbicide treatment.

Each plot, divided into an inner and outer subplot (0.008 and 0.012 ha, respectively), was further subdivided into four quadrants (N, S, E, W) for a total of eight subplots. All trees, tallied for dbh and total height by species in each subplot, were classified as crop trees or volunteers. A dominant/codominant crop tree within each of the eight subplots was selected for detailed stem analysis. Total height was the primary selection criterion. Trees established on large old stumps, considered to have a growth advantage in excess of existing soil conditions on the plot, were avoided. Balsam fir was the primary crop tree species. On plots where red spruce (*Picea rubens* (Sarg.)) or white spruce (*P. glauca* (Moench.) Voss) trees suitable for stem analysis occurred, more than one tree was selected from a subplot.

For each stem analysis sample tree, total height and the height of each annual branch node were measured. Disks were cut from the stem at 0.15, 1.37, 2.13 m, and at successive 0.9- m increments to the top of the tree. Mean radius (half of the diameter measured by a d-tape) was marked on each disk, which were labelled and returned to the laboratory.

A soil pit was excavated near the center of each plot. Horizon thickness, rooting depth, depths to mottling and to root restricting layer were measured along each pit face and averaged for the pit. Soil Conservation Service drainage classes were assigned according to mottling depth. Forest floor and mineral soil

Table 1 The distribution of stem analysis sample trees by species and drainage class

Drainage Class	No. of Plots	No. of Sample Trees		
		Balsam fir	Red spruce	White spruce
Well drained	14	105	11	0
Moderately well drained	6	48	4	3
Somewhat poorly drained	2	16	0	0
Poorly drained	7	49	9	1
Total	29	218	24	4

samples were returned to the laboratory for physical and chemical analyses.

Laboratory

Basal area and number of stems were computed for each subplot and expressed on an area basis. An index of competition, the ratio of squared dbh of the sample tree to the average squared dbh of crop trees in the subplot, was computed for each stem analysis tree (Daniels *et al.* 1986).

Bark thickness and annual radial increment for each stem analysis disk were measured to the nearest 0.01 mm along the mean radius. Annual volume increment was computed for each stem section and summed for each tree. Since (i) several of the plots had been thinned in 1986 and (ii) trees were cut for stem analysis during July and August of 1989 (interrupting radial growth prematurely in some cases), 2-year volume increment was chosen as the response variable.

Stepwise regression was used to identify the variables contributing to the variation in 2-year post-PCT volume increment from the following list of potential variables: 2- year pre-PCT volume increment, competition index, crop tree basal area, and number of crop tree stems. A model to predict 2-year post-PCT volume increment was subsequently developed. Regression with dummy variables (Cunia 1973) was used to assess whether equations predicting post-PCT volume increment could be combined by grouping drainage classes together.

RESULTS AND DISCUSSION

The predominance of balsam fir in the PCT stands is reflected in the species distribution of the 246 conifer stems that were stem analyzed (Table 1). Balsam fir accounted for 90% of the crop tree stems over the 29 plots, with red spruce and white spruce making up 9% and 1%, respectively. In the few instances where it was encountered in a plot, red spruce was (i) seldom in a dominant/codominant position and (ii) often exhibited poor form and vigor, with curled branches and brown foliage at branch tips. White spruce, although very limited, appeared to be as vigorous as the fir.

The better drained soils were well represented in the data collected (Table 1). Unlike the situation with mature spruce- fir stands, locating PCT stands on well drained (WD) and moderately well drained (MWD) sites was not difficult. Many of the WD soils were field classified as Danforth and Masardis series, whereas the poorly drained (PD) soils were classified exclusively as Monarda series. The Danforth series was well represented in sample plots that were established in mature stands earlier in the field season. This will facilitate a limited comparison, using stem analysis data, of early growth rates of PCT

Table 2 Summary of stand and tree morphological data for the 29 plots established in precommercially thinned stands[a]

Variable	Crop Trees	Competitors
Dbh (Cm	7.4	0.8
	(0.5 - 16.8)	(0.1 - 7.6)
Height (m)	5.5	2.1
	(1.8 - 10.7)	(0.6 - 7.0)
Basal area[b] (m^2/ha)	11.0	0.5
	(0 - 32.1)	(0 - 3.7)
Stems[b] (#/ha)	2235	4693
	(0 - 9551)	(0 - 21242)

[a]Means above, ranges in parentheses below
[b]Basal area and number of stems computed for each subplot (8 subplots X 29 plots) = 232 observations

stands with unmanaged stands on the same soil series.

Although pretreatment stem densities were not measured, the number of stumps surrounding crop trees was often visually impressive. Mensuration data collected from the 29 plots indicate PCT was very effective in controlling competition. Basal area of crop and volunteer trees averaged 11 and <1 m^2/ha respectively (Table 2). Although basal area of volunteer trees was low, large numbers of small stems occassionally appeared (Table 2). Balsam fir and willow (*Salix* sp.) were the dominant volunteer species on the imperfectly drained soils, whereas pin cherry (*Prunus pensylvanica* L.) and trembling aspen (*Populus tremuloides* Michx.) dominated on the better drained soils. Red maple (*Acer rubrum* L.) and paper birch (*Betula papyrifera* Marsh.) volunteers were widely distributed across drainage classes. There were occurrences of tall (6-m height) volunteer trees occupying holes in the conifer canopy on a few plots.

During the course of field work, the impact of PCT on radial increment of trees cut for stem analysis was visually evident. Following laboratory measurement, it was readily apparent that the magnitude of increase in radial increment following thinning varied with location on the stem. A graph of radial increment versus stem height (Leblanc *et al.* 1987) for a balsam fir tree from a plot that was thinned in 1981 (the earliest treatment year) illustrates the impact of thinning on tree growth (Figure 2). The magnitude of the increase in radial increment following elimination of competition by PCT (i) varied along the length of the stem and (ii) was greatest at the base. That pattern of radial growth persisted for five years, after which the pretreatment pattern (maximum radial stem growth adjacent to the photosynthetically active crown) began to reemerge. Other studies have demonstrated relatively large increases in radial increment at the base of stems in response to thinning (Myers 1964).

These results reinforce the fact that radial increment at breast height alone is not sufficient to assess the impacts of PCT on tree growth. Volume increment, which integrates radial and height increment over the entire length of the stem, is a better measure of response to PCT. It is interesting to note that a significant increase in height increment was observed the second growing season following thinning.

Two-year pre-PCT volume increment was identified by stepwise regression as an important predictor of 2-year post-PCT volume in-

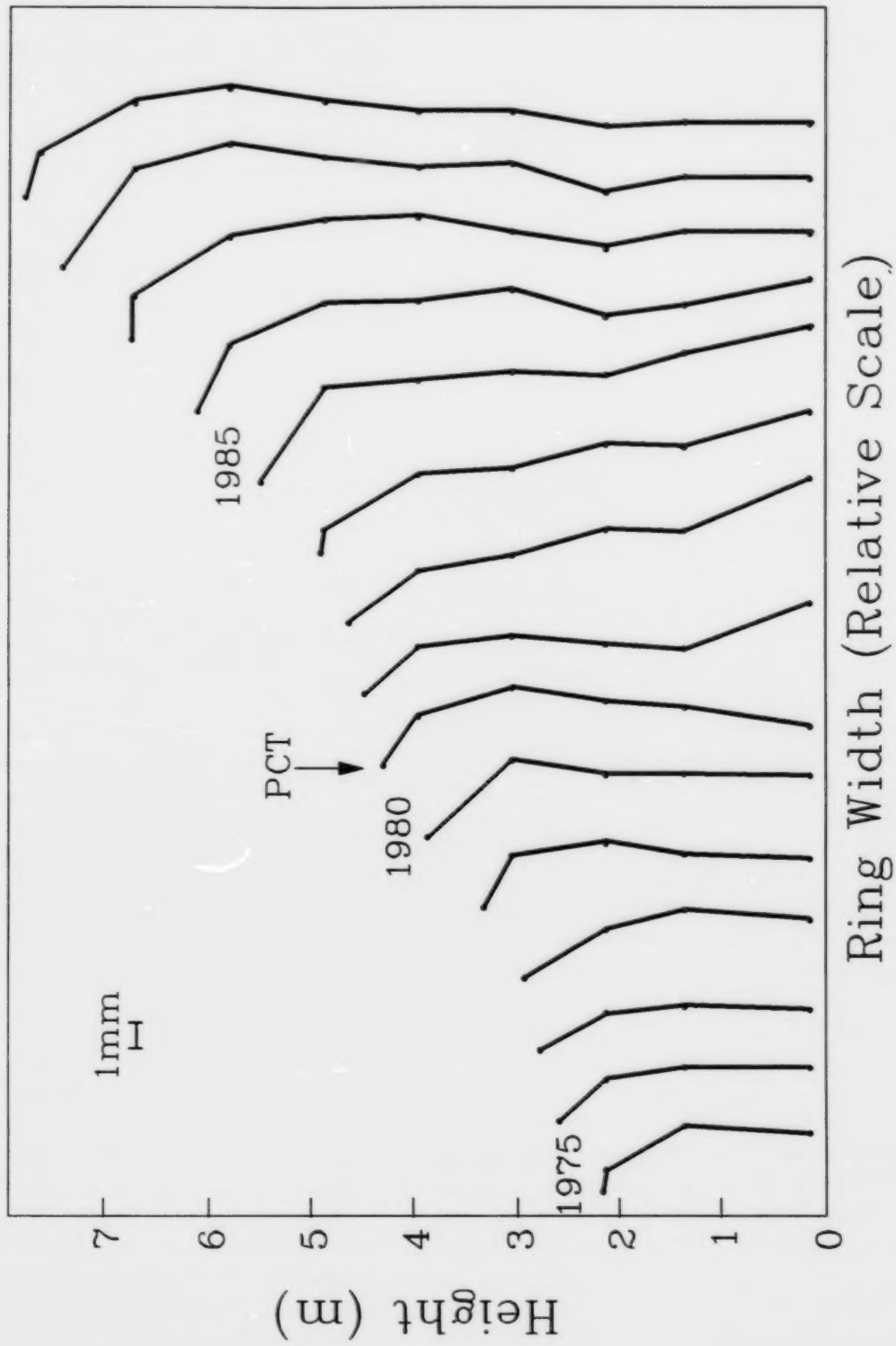

Figure 2 Annual growth layers for a balsam fir tree from the oldest treated plot. The top of each curve represents the apex (0 ring width) of the tree during that year. Ring width at any height in the tree can be estimated by measuring to the right of a perpendicular drawn from the apex to the X axis.

Table 3 Variables contributing to the variation in 2-year post-PCT volume increment identified using stepwise regression[a]

Variable	Drainage Class[b]			
	PD	SPD	MWD	WD
2-year pre-PCT volume increment	**	**	**	**
Competition Index	**	**		**
Crop tree basal area		**		**
Crop tree # of stems		**		**

[a]** denotes statistical significance at $\alpha = 0.01$
[b]PD = poorly drained, SPD = somewhat poorly drained, MWD = moderately well drained, WD = well drained

crement across drainage classes (Table 3). Competition index was selected as an important predictor variable for three of the drainage classes (Table 3). Basal area and number of crop trees were significant only for WD and SPD soils, the latter represented on only two plots. A model predicting post-PCT volume increment from pre-PCT increment and competition index was developed across drainage classes (Figure 3).

The impact of pre-PCT volume increment on post-PCT volume increment is much greater than that of competition index, which represents the basal area of the sample tree relative to the average basal area of its neighbors (Figure 3). In order to evaluate the effects of drainage class on this relationship, we constructed the same model separately for each drainage class. Competition index was not included in the model for the MWD soils. In effect, four response surfaces (one for each drainage class) were modelled in the graphical space depicted in Figure 3, which illustrates only the average response surface for all drainage classes. Drawing those four planes would clutter the picture beyond easy interpretation. Coefficients of determination (r^2) for the four regressions ranged from 0.70 to 0.95, indicating a strong relationship between post-PCT increment and the two independent variables (pre-PCT increment and competition index).

The next step was to determine if the model could be simplified by using a single coefficient for competition index in place of the three separate coefficients for WD, SPD and PD soils (competition index did not add to the ability to predict post- PCT volume increment on MWD soils). Statistically, we tested the null hypothesis that coefficients for competition index were equal for three drainage classes. Based on the resulting F- statistic [1.019 with 2,200 degrees of freedom (df)], the null hypothesis was accepted. A single coefficient for competition index was statistically no worse than separate coefficients for each drainage class.

The simplified model was presented graphically (Figure 4A) by holding the value of competition index at 1. Translated to the surface presented in Figure 3, this can be interpreted as slicing the graph at competition index=1 and plotting the edge of the four planes (one for each drainage class) in one dimension.

Given the simplified model (Figure 4A), an attempt was made to combine regressions by broad drainage classes (PD and SPD, MWD and WD). Two null hypotheses were tested sequentially: (i) the coefficients for pre-PCT increment were equal for drainage class groups (PD=SPD and MWD=WD) and could be combined; and (ii) given equal coefficients,

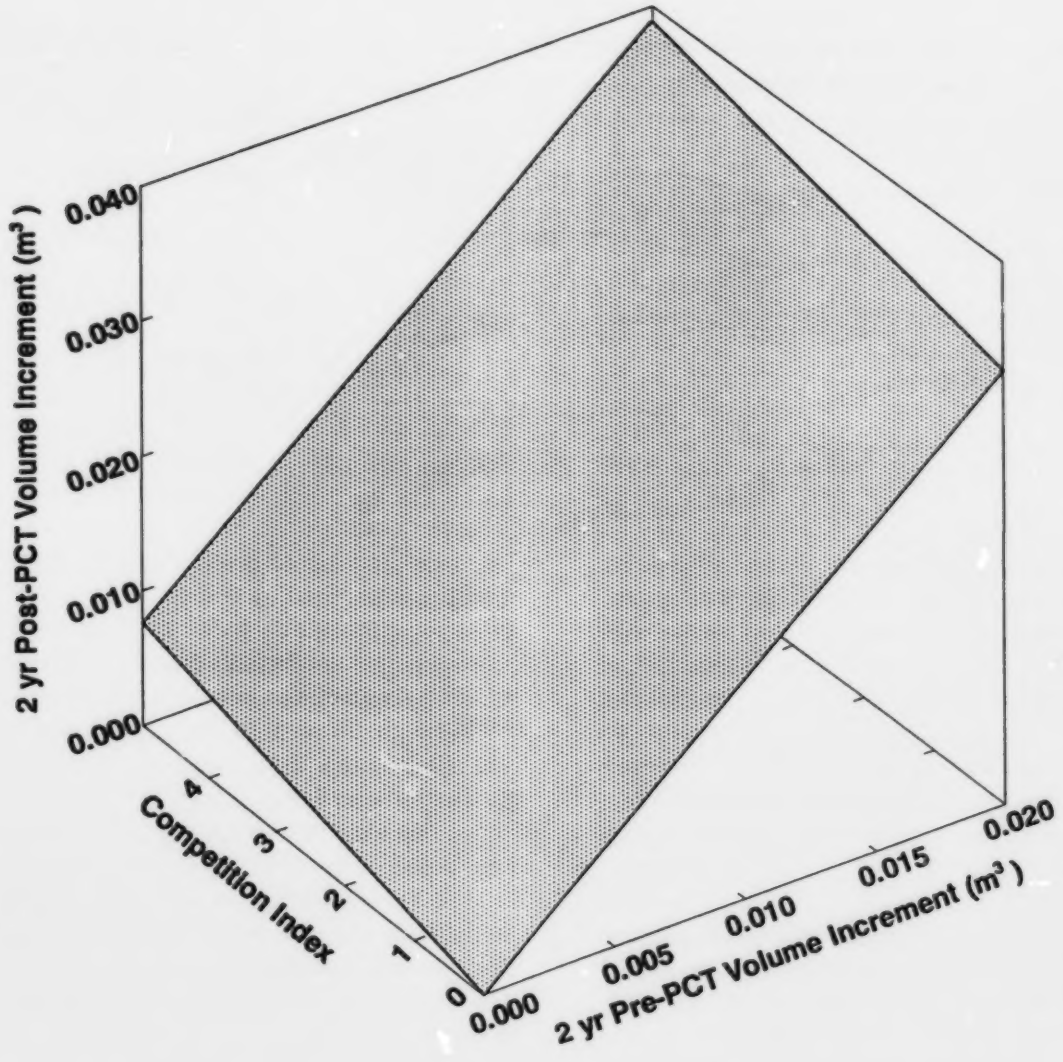

Figure 3 Graphical representation of the regression of post- PCT volume increment on pre-PCT volume increment and competition index across drainage classes.

drainage classes within the larger drainage groups shared the same intercepts. Acceptance of the latter null hypothesis would imply a single regression line for PD and SPD soils, and a single line for MWD and WD soils. The F-statistics for null hypotheses (i) and (ii), 0.259 with 2,204 df and 2.53 with 2,206 df, respectively, resulted in acceptance of both null hypotheses.

The final model is illustrated graphically in Figure 4B. The fact that the regression of post-PCT volume increment on pre- PCT volume increment has a slightly higher intercept for WD relative to MWD soils (Table 4) is due to competition index, which was statistically insignificant and not included for the MWD soils. The coefficient for competition index is positive, resulting in a greater apparent intercept for the WD soil (Table 4).

Coefficients for the resulting model illustrate the differential degree of volume increment response by drainage class (Table 4). Two-

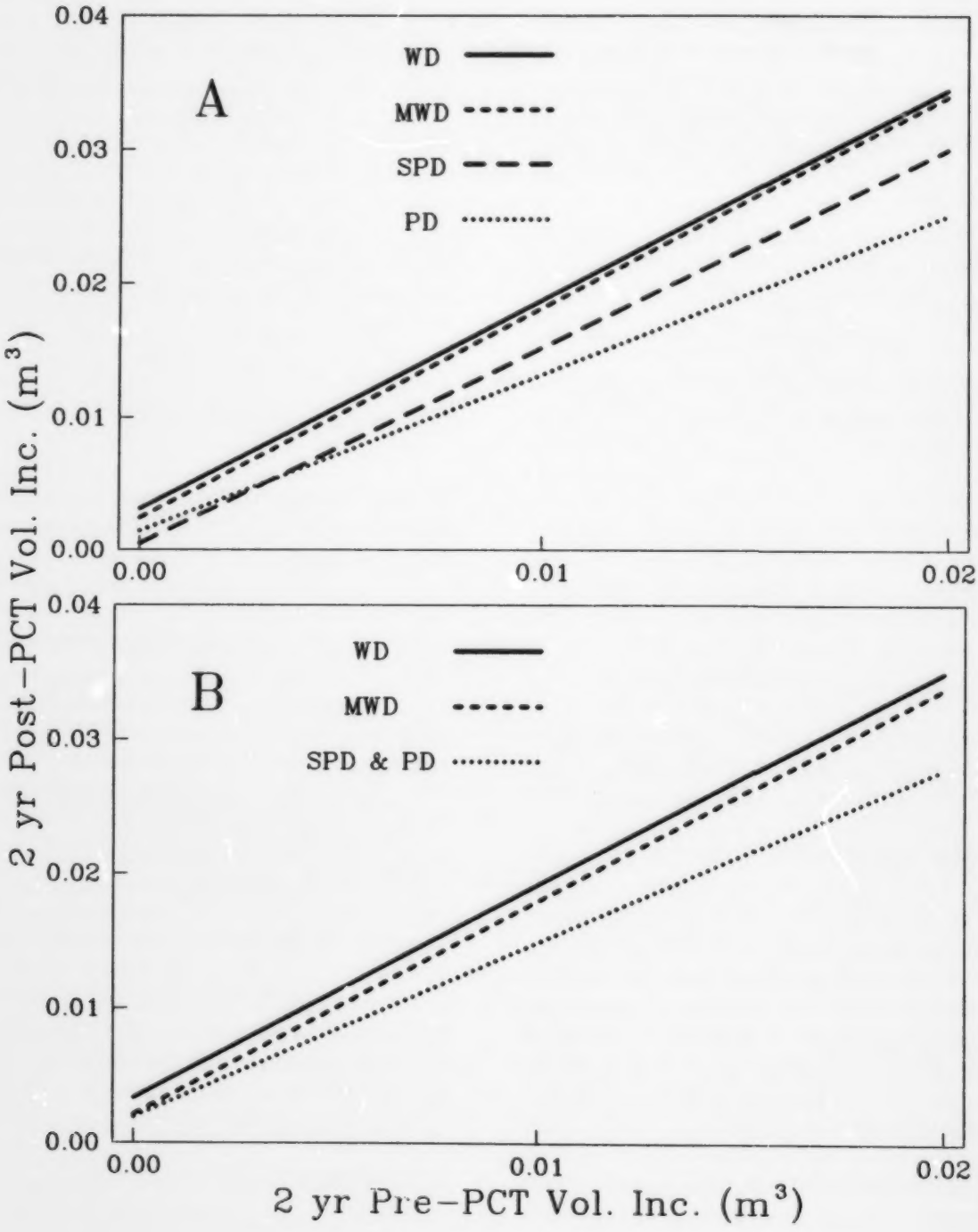

Figure 4 The relationship between 2-year post- and pre-PCT volume increment when competition index is held constant at 1.0 for the initial model (A) and the final model (B) in which drainage classes were combined. (PD = poorly drained, SPD = somewhat poorly drained, MWD = moderately well drained, and WD = well drained).

Table 4 Coefficients for the regression of 2-year post-PCT volume increment on 2-year pre-PCT increment and competition index illustrated in Figure 4B[a]

Drainage Class[b]	Coefficients		
	β_0	β_1	β_2
PD, SPD	0.001	1.293	.002
MWD	0.002	1.583	0
WD	0.002	1.583	.001

[a]Model $y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$ where
y = 2-year post-PCT volume increment (m^3)
X_1 = 2-year pre-PCT volume increment (m^3)
X_2 = competition index = $\frac{\text{dbh}^2 \text{ sample tree}}{\text{avg. dbh}^2 \text{ of competitor trees}}$

[b]PD = poorly drained, SPD = somewhat poorly drained, MWD = moderately well drained, and WD = well drained

year volume increment for trees on the better drained (WD and MWD) soils following thinning was 1.6 times that prior to thinning. In contrast, volume increment following thinning on the imperfectly drained (PD and SPD) soils was 1.3 times that prior to thinning. In addition to slower radial growth on the imperfectly drained soils, the relative rate of increase following thinning is lower. Thus, differences in growth response are magnified on the better drained soils.

CONCLUDING REMARKS

The effect of PCT on radial growth of balsam fir was visually apparent, even on the PD soils. Volume increment provided an excellent measure of thinning response. Although we observed an increase in height increment in the second year following thinning, the increase in volume increment was attributed largely to radial increment.

The terminal leaders had small diameters and accounted for a very small proportion of stem volume.

Volume increment of individual balsam fir trees following PCT reflects differences in site quality. The effects of drainage class, well documented from work in mature unmanaged stands, are readily apparent at an early point in the development of managed stands. The duration of this differential thinning response has yet to be determined.

Clearly, the relationship between site quality and growth response to silvicultural treatment needs further study. Currently, work is being planned in older, managed stands during the 1990 field season. The underlying question remains: How many years are removed from the rotation age of precommercially thinned stands as site quality increases from low to high? Erdle (1987), examining the impacts of precommercial thinning on the wood supply of New Brunswick, used figures of 20 and 25 years as the amount of time required for spaced stands to reach operability (average tree volume = 0.14 m^3) for good and average sites, respectively. Only by following managed stands across the range of site quality through an entire rotation will this question be adequately addressed.

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FILL PLANTING TO ACHIEVE YIELD TARGETS IN NATURALLY REGENERATED STANDS

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INTRODUCTION

One of the problems with natural regeneration is that stocking (*i.e.*, the proportion of an area having acceptable regeneration) can be highly variable. In one region of New Brunswick for example, more than 40% of the area cut between 1977 and 1983 had stocking levels less than 30%, about 40% had between 30% and 60% stocking and 20% had more than 60% stocking 5 years after harvest (Figure 1).

At the extreme stocking levels, silvicultural decisions can be fairly straight forward. Areas with very low or no stocking require planting (assuming soil-site conditions are amenable), while fully stocked areas can be left to develop naturally or tended later. The question is: How should stands with intermediate stocking levels be treated? On one hand, the regeneration is insufficient for producing acceptable yields, on the other hand, it is too abundant to completely dismiss.

One frequently discussed silvicultural option for dealing with such stands is fill planting. Interplanting, in-fill planting, gap planting, supplementary planting, replacement planting, repair planting, replanting, blanking, beeting, and beating-up are all synonymous terms. The fundamental objective of each is the same; namely, to increase stocking by planting. The terms differ primarily in context and regional preference. Some, for example, are used in reference to natural stands, *e.g.*, gap planting, while others are used in reference to plantations, *e.g.*, repair planting. Some are primarily used by the Scandinavians (beeting, beating-up) while others are favored by the Australians (*e.g.*, blanking). For simplicity, the generic "fill planting" is used here.

This paper addresses two basic questions about fill planting: 1) What are the treatment:response relationships? and 2) How and when should fill planting be employed? To answer these, fill planting under extreme spatial distribution patterns is explored. In doing so, the bounds on the yield response can be identified and the different approaches to fill planting demonstrated.

YIELD RESPONSE TO FILL PLANTING

Density and Spatial Distribution Considerations

Yield information is important in determining if fill planting should be carried out since it indicates the potential benefit of the activity. Ideally, a multi-species, individual tree, distance dependent, growth and yield model would be required to examine the response of fill planting under various tree density and spatial distribution configurations. Unfortunately, a suitable model is not currently available for the spruce-fir-northern hardwood region of northeastern North America. To gain some understanding of the different yield responses however, a stand level plantation model developed by the New Brunswick Department of Natural Resources and Energy (DNRE, 1989a) was used to predict yields under extreme density and spatial distribution configurations.

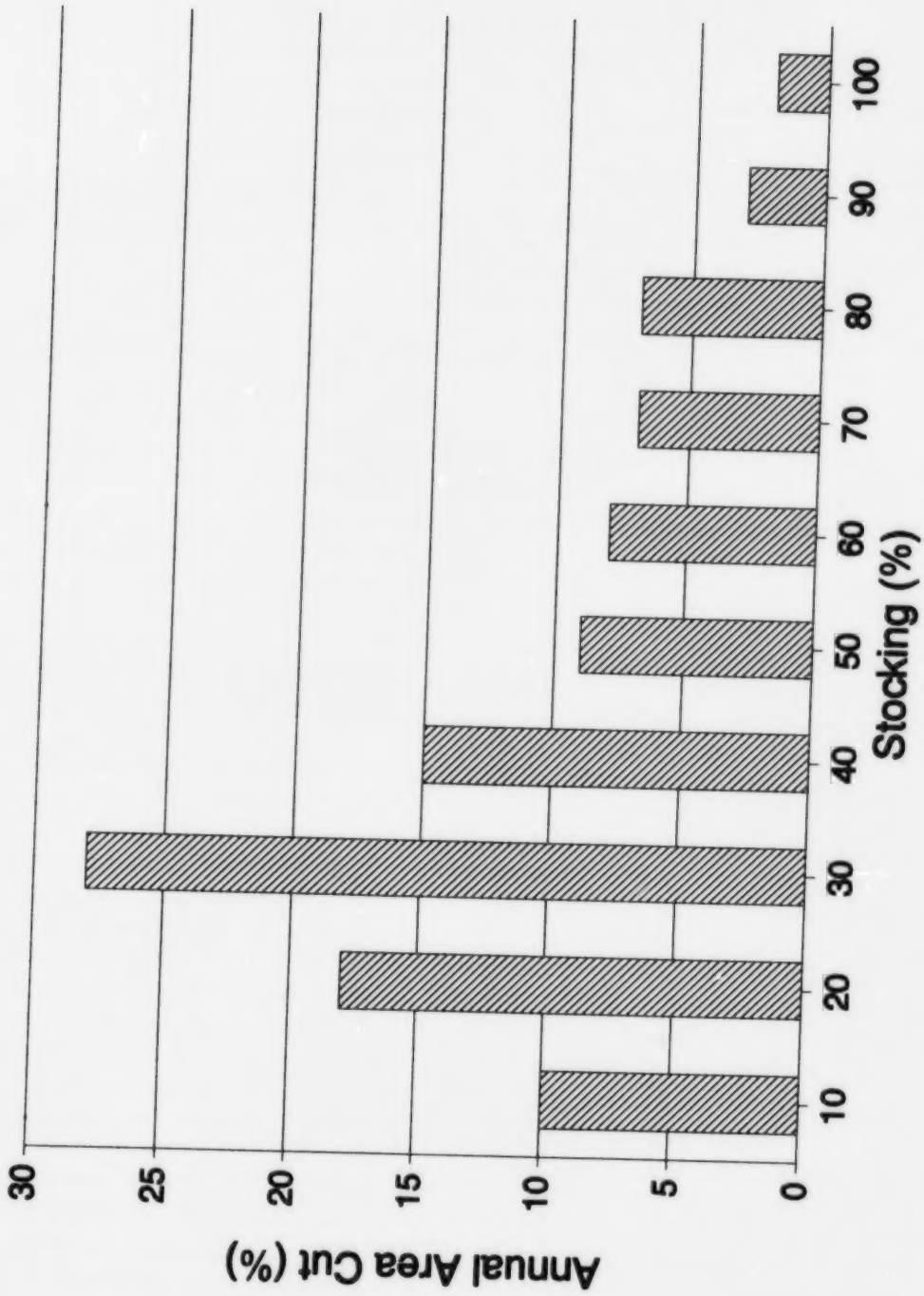

Figure 1 Softwood stocking in one region in New Brunswick 5 years after harvest (1977-1983

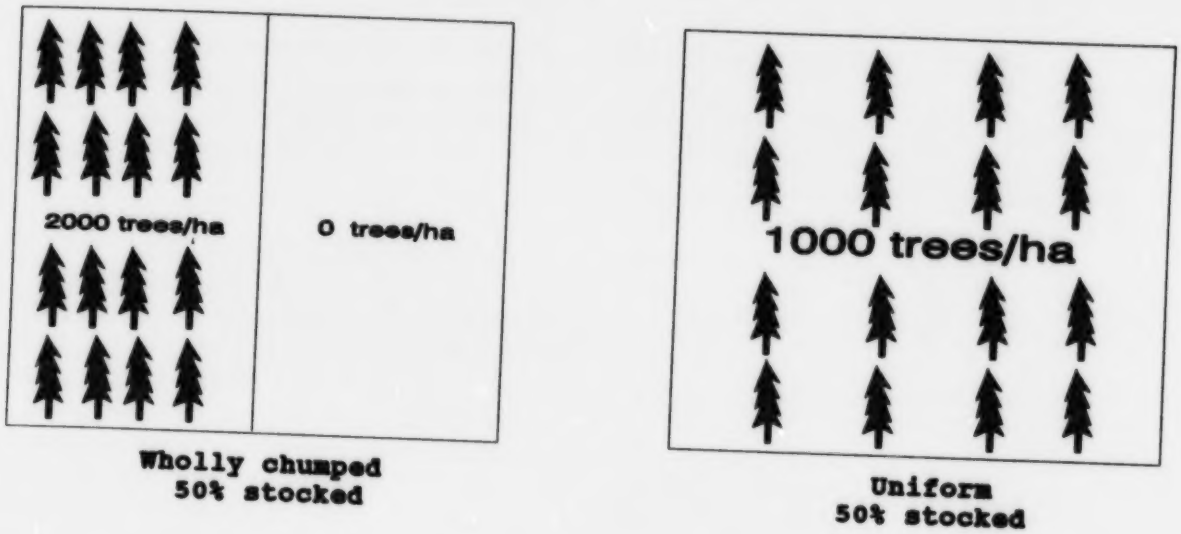

Figure 2 Stocking under opposing spatial distribution patterns. In both examples, average stocking is 50%

Figure 2 illustrates the conditions examined. In one, the trees are uniformly distributed across the area and simply exhibit low density (1000 trees/ha instead of the 2000 trees/ha). In the other, trees are wholly clumped wherein one portion of the area they exhibit the average desired density while in the other portion of the area no trees are present. In this example, the stocking under each spatial distribution pattern is the same.

Figure 3 illustrates the theoretical relationship between stocking and yield under these extreme conditions using black spruce growing on a SI50 = 17 m site for 50 years. For the wholly clumped situation, yield is expected to be directly proportional to stocking. That is, if 50% of an area is 100% stocked and 50% has no stocking, *i.e.*, the area 50% stocked, yield is 50% of what it would be under 100% stocking. In comparison, when trees are distributed uniformly across a site, *i.e.*, no large voids just low density (1000 rather than 2000 trees/ha), yields are expected to be 80% of what they would be under 100% stocking.

These two density/spatial distribution configurations represent extreme situations that probably seldom occur. Nevertheless, they bound the yield/stocking relationship. In reality, the yields for any one stocking level probably lie somewhere between the two depending on the density/spatial distribution configuration of the trees. In Figure 3 for example, actual data for Norway spruce (Braathe 1980) are given. Similar information is presented by Doucet (1991) in this publication. Both depict a situation where stocking tends to be fairly well distributed but with small unstocked gaps interspersed throughout the area.

Seedling Size Characteristics

A fundamental question with fill planting is: What is the likelihood that a fill-planted seedling will contribute to the final yield? It makes little sense to fill plant if seedlings eventually become suppressed and die. Along with the spatial distribution of stocking, proximity to neighbors, seedling growth rate, and seedling size are important, interacting determinants.

With increasing certainty that the growth rate of planted stock will equal or exceed that of natural regeneration, the gap size or minimum distance between naturals and planted stock can be reduced to the spacing desired. However, if planted stock lags behind natural

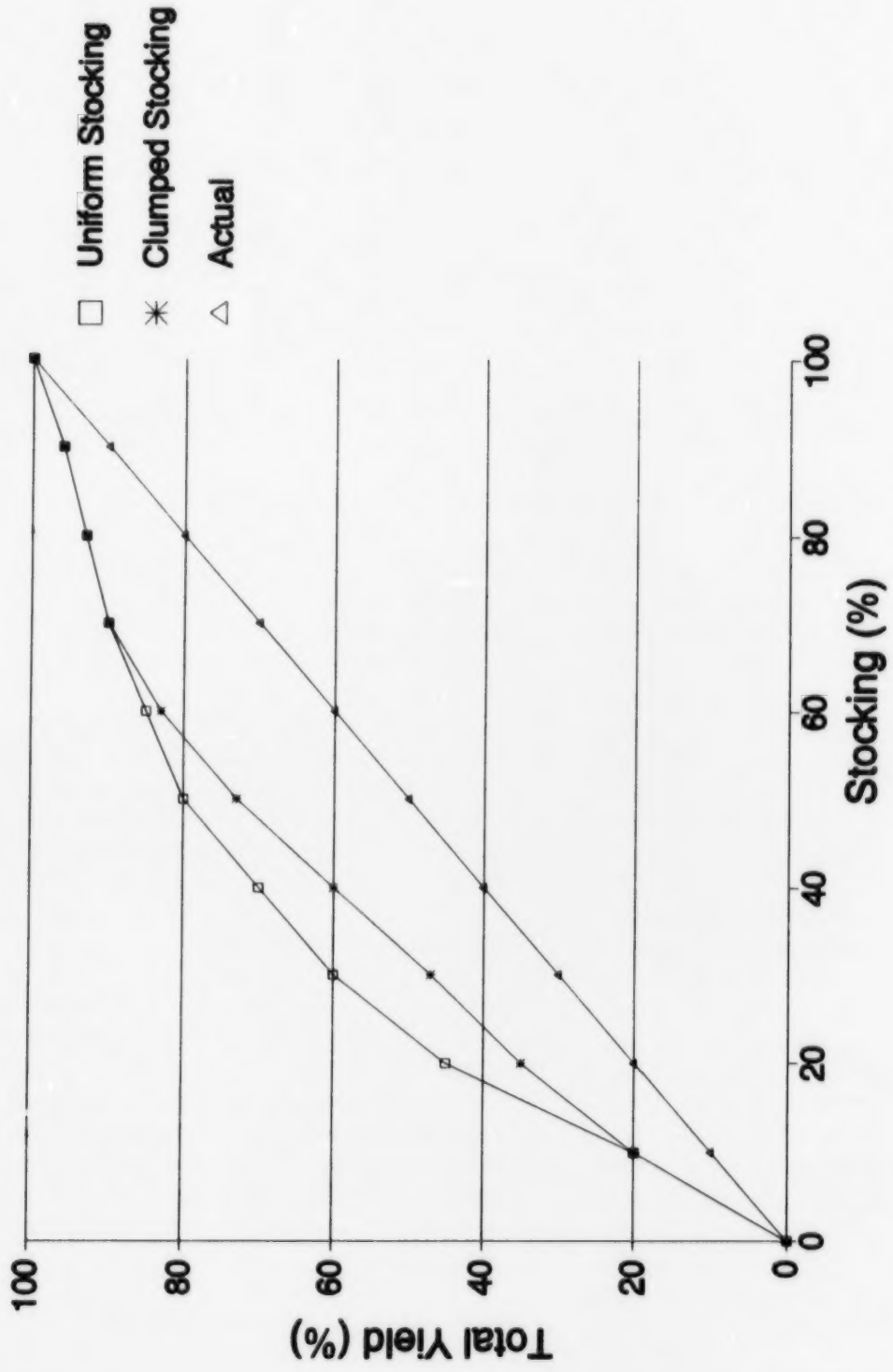

Figure 3 Effect of stocking on merchantable yield under opposing spatial distribution patterns

stock, more distance between the two is required to prevent planted stock from becoming dominated and contribute little to the total volume.

The initial size of planted stock relative to naturals plays an important role in the distance/growth rate relationship. Not only can relative size affect the chances of having equivalent growth rates, it more importantly predisposes a seedling to some subordinate position in the canopy. A small seedling, for example has a greater chance of being overtopped by a larger adjacent natural than if both were the same size; even if both are growing at the same relative rate.

Simulations were conducted with DNRE's model to assess the volume contribution made by various sizes of fill planted stock across the stocking range. The objective was to identify the minimum distances required for success (Figure 4). Since a uniform tree distribution was assumed, initial stocking levels could be interpreted as distances between fill-planted stock and naturals. At least initially, relative growth rates for naturals and planted stock were assumed equal but as seedlings grew and crowns interacted, larger seedlings usually assumed a dominant position in the canopy and slowed the growth of smaller neighbors.

Only at very low stocking levels did small stock permit potential stand volume gains to be realized (Figure 4). Fill planting with seedlings half the size of existing naturals generated no volume when stocking was above 60%. This suggests that the minimum distance between the two must be at least 3.0 m before any volume gain from fill planting is realized. Stock whose size was 75% that of naturals however, contributed 50% of the volume gain that planting full size stock made. This translates into a 2.5-m minimum distance between naturals and fill plants.

FILL PLANTING STRATEGIES

Basically, there are two fill planting strategies: 1) large gap planting and 2) partial planting across an entire cutover. These strategies differ in their application, administration, costs, and potential yield responses.

Large Gap Planting

Under the large gap planting strategy, relatively large unstocked areas within a cutover are located and the boundaries identified prior to planting. Planters are then specifically directed to those areas and plant as if it were a typical full planting operation. Seedlings are planted at regular intervals as quickly as possible, and the primary decision facing planters is microsite selection. Planting is carried out in a manner that promotes seedling survival and growth, and while there is no question in the planter's mind that a seedling will be planted at every planting spot, when an acceptable natural occasionally occurs, the planter is usually instructed to forego planting and move to the next location. The strategy is essentially no different from that used in plantation establishment except that planting is confined to relatively large unstocked areas within an otherwise fully stocked cutover.

The success of the strategy depends on identifying unstocked areas prior to planting. A stocking survey must not only indicate the extent of stocking but also disclose the location of unstocked areas. It is this mapping aspect which is difficult, time consuming, and costly, but absolutely necessary if the strategy is to succeed. Landings or systematic harvesting disturbances (skid trials) that reduce stocking in direct proportion to the area they disturb can probably be found fairly easily. However, finding natural voids is more difficult. It is unlikely that a survey relying simply on quadrat sampling with small, milacre plots distributed at a rate of 1 per ha is adequate. Some combination of sampling strategies previously described in this publi-

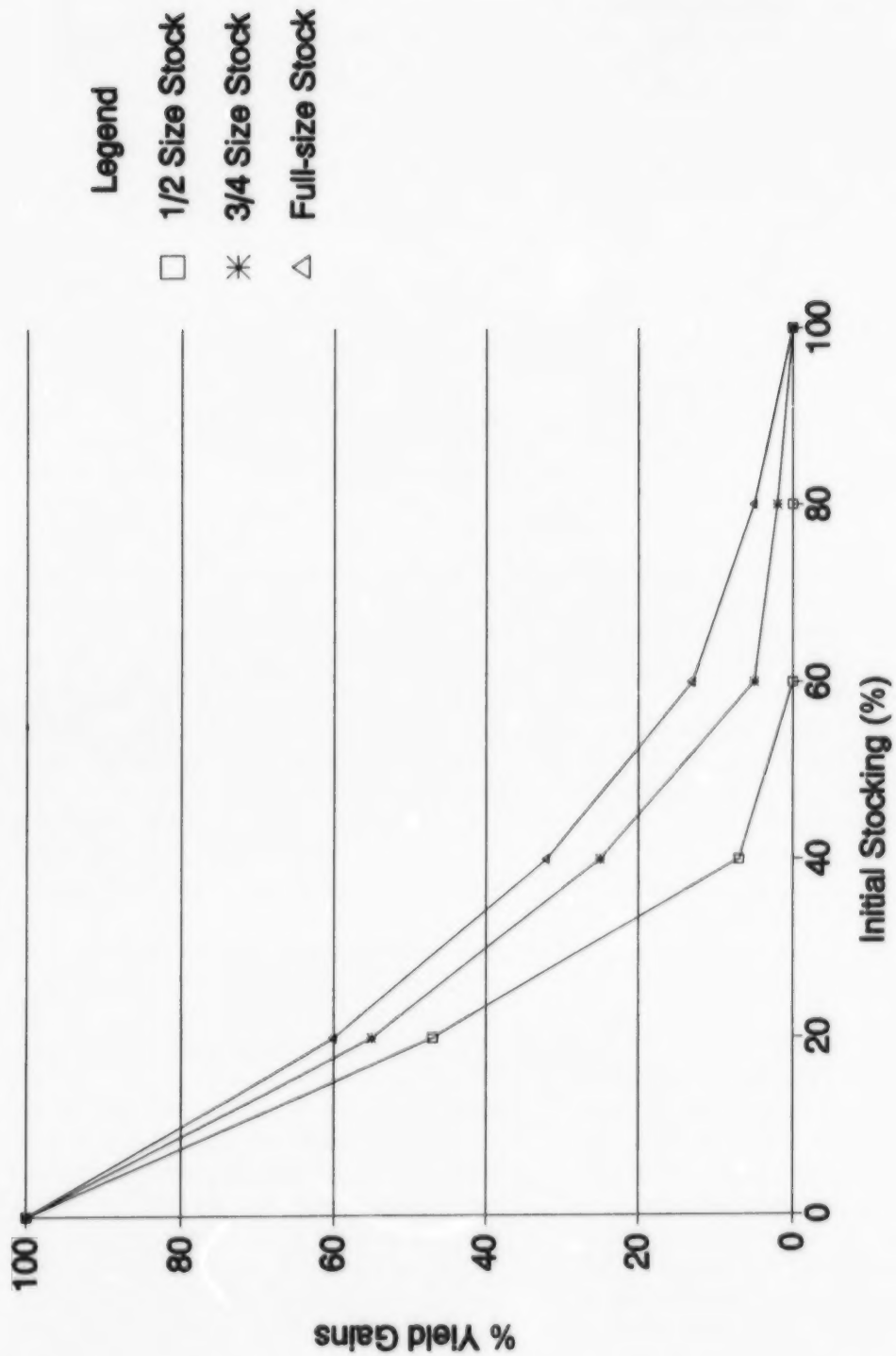

Figure 4 Yield gains from fill planting stock of various sizes

cation (Maass 1991) at an increased sampling intensity is probably required, although no information specifically addressing the mapping problem is available.

The minimum size of an unstocked gap that should be considered for planting under this strategy is variable, but primarily a function of the operational costs associated with finding and marking gaps, getting planting crews to those gaps, and getting the planting done. As gap size decreases, the cost of locating and planting gaps increases, and planting productivity declines because planters spend more time moving from gap to gap than they do planting. As a consequence, the minimum operational or economic gap size is fairly large. One company in Maine for example, uses a 2-ha (5-ac) minimum.

Because gap size is large in this strategy, intraspecific competition is essentially nonexistent. Tree size, proximity to neighbors, and the growth rate of planted stock relative to naturals is irrelevant since few naturals are present. Consequently, large gaps behave as independent stands and yield increases in direct proportion to the change in stocking.

There are a number of important implications relative to when large gaps should be planted and how they should or could be treated both currently and in the future. Since large gaps are essentially independent stands they could be planted at any time and the longer planting is delayed, the easier they are to find. The goal is usually to have gaps on the same operating schedule as the rest of the stand, however, so locating gaps and planting soon after harvest is an advantage. Competition is at a minimum and planting is easiest shortly after harvest, also.

Site preparing gaps to facilitate planter access and mobility, or to ameliorate the site to improve seedling survival and growth could be employed in large gaps with minimal disturbance to the stocked portion of the cutover. Also, since the density and spatial distribution of crop trees is controlled in these gaps, precommercial thinning (PCT) may be excluded from planted gaps even though it may be a desirable treatment to impose at some later date across the remainder of the cutover. A cost savings may result as a consequence.

Planting large gaps only has a drawback in that gaps smaller than the minimum operational size remain unstocked. This represents an opportunity cost since yield gains for the entire cutover will be less than theoretically possible. The minimum gap size varies with species and rotation length and from trials with Norway spruce, Gimmel (1988) suggests a minimum size between .008 - .015 ha. Using the spacing factor concept of density management (Wilson, 1979), a .004 - .016 ha minimum was estimated for balsam fir growing on a SI50 = 17 m site on a 50-year rotation. This represents the size of an open grown tree crown and assumes that another tree could exist any where from the edge of that crown to 3.6 m away from that edge (*i.e.*, the radius of another open grown tree crown away). In effect then, those unplanted voids between .004 - 0.016 ha and the operational minimum (2 ha, for example) go unplanted and remain "unstocked". The cost of this lost opportunity depends on the frequency with which such areas occur and must be balanced against the cost of carrying out the fill plant.

The advantages and disadvantages of fill planting large predesignated gaps are summarized in Table 1. The primary advantages are that planting is most efficient under this strategy because planters spend little time identifying the presence and quality of existing natural vegetation and more time planting. Every planted seedling has the potential to be a crop tree because density control is achieved at the time of planting. Few seedlings are wasted and subsequent tending, such as precommercial thinning is not required.

Table 1

Strategy	Advantages	Disadvantages
Large Gap Planting	- volume gains are proportional to the size of the area planted - Wide planting window - Maximum planting efficiency - Minimum seedling wastage - Opportunity to site prepare voids	- High overhead cost to find and identify large gaps - Lost opportunity in not planting gaps whose size is less than the operation permits
Partial Planting Across An Entire Cutover	- All gaps regardless of size can be filled - No elaborate or expensive pre-plant surveys required	- Narrow planting window - Low planting efficiency - A large number of seedlings may never contribute to stand volume - Planters must be able to identify acceptable natural regeneration - Size-growth-distance relationships between planted stock and naturals must be undertood so appropriate stock can be provided

The cost of this strategy is that unstocked areas have to be identified and located prior to planting so that planting crews can quickly move from one gap to another. In addition, opportunity costs are incurred in the form of lost volume from gaps smaller than the operational minimum.

Partial Planting Across An Entire Cutover

Under this fill planting strategy, a planting crew walks an entire cutover, stopping at nominal planting locations to assess the presence and quality of naturals, and planting only those spots where acceptable natural regeneration is missing. If the nominal desired density is 2500 stems/ha, trees should occur at 2-m intervals and planters should stop to assess the necessity of planting at those intervals. If natural regeneration is absent within some specified distance of nominal location, a seedling is planted. If present, the planter moves another 2 m to the next location. Essentially, the process mirrors that used in plantation establishment except that seedlings are not necessarily planted at every location, and depending on the stocking, a planter may spend more time walking than planting.

Success with the strategy depends on 1) identifying acceptable natural regeneration and 2) planting stock that will survive and grow to make a contribution to total stand volume. Identification of acceptable natural regeneration implies that it can be seen and that its quality relative to growth and yield can be ascertained. To see advanced regeneration, planting must be conducted in early spring prior to leaf-flush and ideally end with leaf-flush. Fall planting may be suitable if a high proportion of the seedlings can survive the winter. Planting outside this relatively narrow window is likely to result in over planting since existing naturals simply may not be seen.

The quality of the natural regeneration must also be assessed along with identifying its

presence. If a natural is not acceptable, a seedling should be planted and hopefully it will out-perform the natural stock. Unfortunately, criteria to assess seedling quality are currently ill defined.

Finally, if a planted seedling doesn't eventually become a dominant or co-dominant tree within the stand, its contribution to total stand volume will be trivial and the expense of planting wasted. Therefore, the size and growth rate of planted stock relative to advanced regeneration is critical. A planted seedling must never lag behind the natural regeneration and become dominated.

Table 1 enumerates the advantages and disadvantages of fill planting under this strategy. In many respects, they are opposite those under the large gap only, fill planting strategy. The upfront expense of gap identification required with large gap planting is replaced by the added burden placed on planters to identify acceptable natural regeneration. It is critical with partial planting across an entire cutover that planted stock grow as well as the natural regeneration and eventually assume at least a co- dominant position in the canopy. Consequently, an understanding of the size-growth-distance relationships between naturals and planted stock is essential to ensure that planted stock makes a significant contribution to stand volume. As yet, these relationships are poorly defined. The cost of planting under this strategy is likely to be more than under large gap only fill planting because an entire cutover is walked and planters are paid to recognize acceptable regeneration and not plant. Unfortunately, the general trend is to over plant since the adage "while I'm here I might as well stick a seedling in the ground" prevails. Such a perspective certainly increases the probability of attaining full stocking; however, the added costs of achieving only slight volume gains may be enormous. Finally, while full stocking is achieved, density control is not, and subsequent precommercial thinning may be required.

Other Strategies

Other approaches to fill planting are possible but likely represent some combination of the two just described. For example, fill planting may be confined to landings or skid trails, or other small gaps. Landings and skid trails are well defined candidates but may require soil tillage and fertilization to eliminate the effects of soil compaction. With skid trails, consideration must also be given to their width. Unless they are wide enough and the fill planted seedlings large and vigorous enough, planted stock may never be able to compete with naturals growing along the edge of the trail and the planting effort wasted.

Small gap planting represents a situation where gaps as small as 0.008 - 0.015 ha (5-7 m radius in size) are fill planted. These gaps represent those smaller than considered in the "operationally" minimum case. Such gaps would not be identified prior to planting, but planters would examine a cutover, searching for and planting those gaps whose size was at least this minimum and larger. As such, planters would not necessarily proceed through a cutover stopping a 2-m intervals (the nominal spacing) rather they would systematically peruse an area searching for minimum sized gaps. Once identified, gaps would then be planted at the nominal spacing, *e.g.*, 2 m. No direct attempt would be made to fill plant gaps smaller than this minimum size.

In a sense, it represents a compromise between large gap only planting and planting at the nominal spacing. In terms of growth, such a strategy would maximize the yield gains from fill-planted stock and seedling wastage would be minimal. Implementation, especially gap identification, would be difficult, however.

THE FILL PLANTING DECISION

The decision to fill plant or not should depend on the costs relative to the benefits. Unfortunately, little cost information with regard to

the fill planting strategies described is available. For the purposes here, however, a cost function based on the reimbursement rate paid by the Province of New Brunswick (DNRE 1989) with a $0.13 seedling cost was used. The function has been extended beyond the stocking bounds New Brunswick considers for fill planting (for illustration purposes only) and even though each of the two fill planting strategies described is likely to have its own cost structure, only one cost function was used.

For the purposes here, the marginal benefit (or revenue) of fill planting is the dollar value of the additional yield obtained by bringing stocking up to 100%. A stumpage price of $\$6.00/m^3$ and a maximum yield (at 100% stocking) of 250 m^3/ha 50 years were used. Marginal revenue was discounted by a 0% interest rate. We recognize that land managers typically employ positive rates of return and that interest rate significantly affects the fill planting decision. However, our goal was to establish an upper limit of feasibility. Figure 5 illustrates the marginal analysis for both the uniform and wholly clumped stocking patterns.

Under the assumptions made, fill planting a wholly clumped cutover is economical only when the stocking is below 80%. With uniformly distributed natural regeneration it is economical only when the stocking is below 38%. The marginal revenue lines rotate downward as the interest rate or discounting factor increases, generally suggesting that fill planting is feasible only at lower stocking levels. If the interest rate is 1%, for example, the revenue from fill planting exceeds the cost when the natural regeneration stocking is below 60% under the wholly clumped tree distribution pattern and 20% for the uniform pattern. Higher interest rates may make fill planting uneconomic at any stocking level or stocking pattern. Obviously, the criteria for fill planting are going to change as revenues and costs change and these should be well defined prior to making a commitment to a particular fill planting strategy.

The decision to fill plant is not an isolated event and must also be made within the context of overall stand and forest level prescriptions. Fill planting is a treatment applied in combination with others over the life of a stand to achieve some objective. By itself, it may be more cost effective than eliminating the existing natural regeneration and full planting; however, if precommerical thinning is to follow fill planting to reduce stand density and gain spatial control over the trees, the combined cost of fill planting and precommercial thinning may exceed the cost of eliminating the natural regeneration and artificially regenerating the entire cutover.

Lastly, the need or utility of fill planting must be considered in terms of the forest level demands. If each stand is an integral part of the forest, its dynamics must also be put in that context.

CONCLUSIONS AND RESEARCH REQUIREMENTS

Uncertain stocking levels pose a major problem when relying on natural regeneration and fill planting is one silvicultural option foresters should consider in their regeneration strategies. Regardless of the form it takes, several questions must be answered to determine the effectiveness of fill planting. These include: what is the likelihood that the planted stock will survive and grow to assume a dominant or co-dominant position in the canopy - that is, will it contribute to stand volume? What is the cost of implementation relative to that volume gain? Is site amelioration or other silviculture required for success?

Like most silvicultural treatments, the suitability and implementation of fill planting is not straight forward. Rather it is complex and ever changing depending on a land manager's objectives, constraints, alterna-

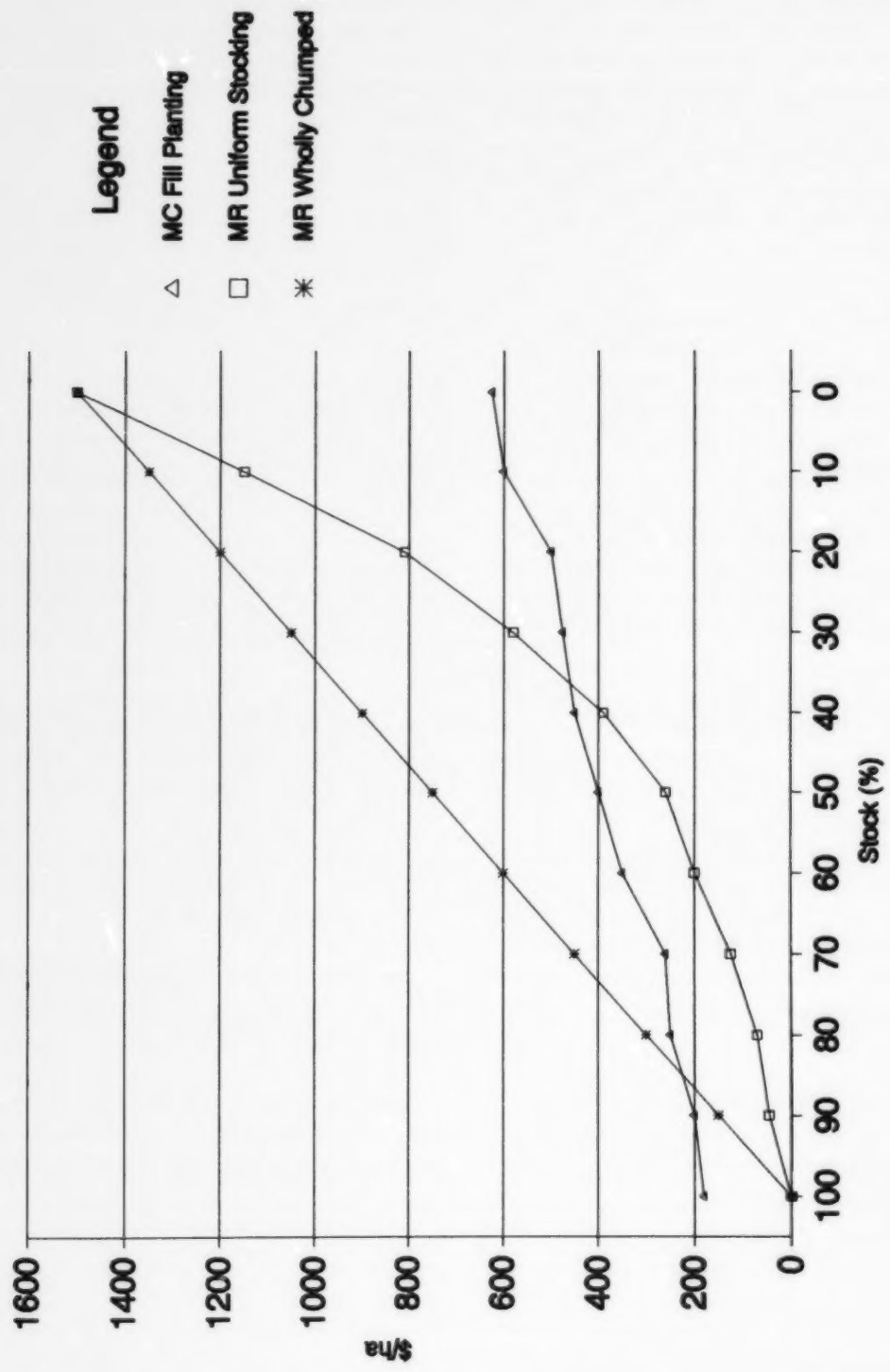

Figure 5 Cost-benefit analysis of fill planting

tives, and philosophy, not to mention the character of the cutovers being considered. To help in decision making under such an environment, silvicultural decision support systems which utilize reliable information are needed. Unfortunately, much of the information needed for such systems is currently not available. The following describes these information requirements:

1. Cost information for inventorying and carrying out fill planting operations. Ideally this should be in the form of productivity information to which dollars can be attached at the discretion of the user.

2. An efficient sampling system that provides spatial information on the size, frequency, and, in the case of fill planting large gaps only, location of unstocked areas.

3. Assessment criteria on natural regeneration quality and performance.

4. A distance dependent, individual tree growth and yield model to investigate size-growth-distance relationships between natural and planted seedlings as well as provide site specific growth and yield information relative to various stocking situations.

5. Empirical information on size-growth-distance relationships between natural and planted seedlings in the form of designed field trails or other experimental research to validate growth and yield models and provide real life examples of the various approaches.

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EVALUATING REGENERATION STRATEGIES UNDER RISK

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INTRODUCTION

On Crown lands in New Brunswick, the selection of a regeneration strategy is based on the postharvest stocking of desirable softwood species. If postharvest stocking is greater than 60%, then natural regeneration is the usual reforestation strategy. If stocking is less than 40%, site preparation followed by planting is preferred. The decision is less clear when stocking falls between these percentages.

This paper presents a model that can help forest managers choose a regeneration strategy. The focus is on the "grey" zone between 40 and 60% stocking; however, the model could be formulated to include a wider range. The model is used for making decisions under risk. The decision maker is here identified as the field forester. The decision level is the stand. Obviously, stand level decisions when taken as a whole have an impact on forest level decisions, but this relationship is not considered here.

The model incorporates risk with regard to (1) the probability of establishing a stand with 75% stocking or more, (2) the probability of having certain density (stems per ha) or competition levels, and (3) the probability of having certain final yields. That is, the model reflects reality in that the outcome of most silvicultural treatments is never certain and yet some treatments have a greater chance of success than others.

THE MODELLING TECHNIQUE

A probabilistic decision tree was chosen as the modelling approach. A decision tree is a graphical representation of the sequential decision making process typified by silvicultural decisions. Figure 1 shows a simple decision tree for selecting a regeneration strategy for a given initial stocking level. Working from left to right, the tree indicates the natural or logical direction in which decisions are made. The forest manager must first choose a regeneration strategy (*e.g.*, natural regeneration, artificial regeneration such as site prep and planting, or a combination such as fill planting). Two outcomes are possible for each alternative: one, the site is adequately stocked, that is, has 75% stocking by the fifth year; or two, stocking is inadequate. Each outcome, or state of nature, has an associated probability of occurrence. Ultimately each chain of events has a pay off, in this case a final harvest volume or revenue.

The parts of the decision tree are named for the type of decision or outcome they represent. The intersections or junction points are called nodes and the connectors or arcs joining the nodes are called branches. When the branches leaving a node involve a decision made by the decision maker, the node is called a decision node and is represented by a square. Branches representing possible outcomes of an action emerge from state of nature nodes designated by circles. In Figure 1, node 1 is the decision node for the type of regeneration technique and nodes 2, 3, and 4 are state of nature nodes for different stocking levels.

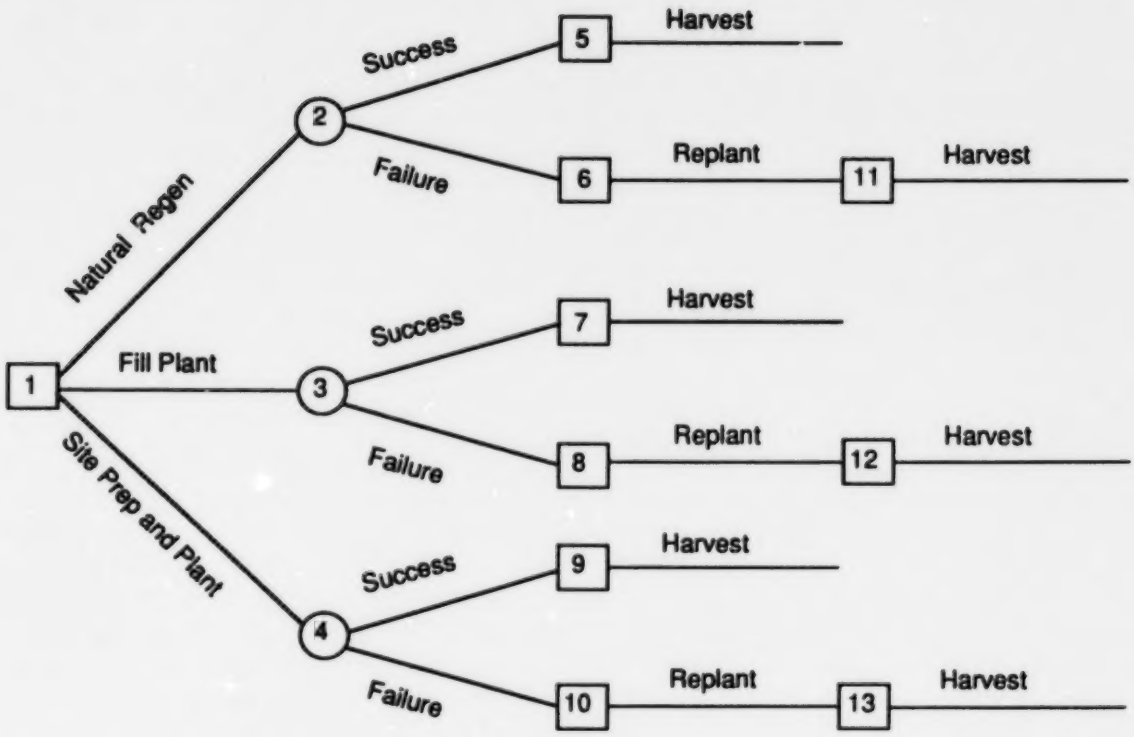

Figure 1 A simple probabilistic decision tree for choosing a regeneration system

MODEL DEVELOPMENT

The decision tree in Figure 1 is not a complete portrayal of the full decision process for selecting a silvicultural strategy. A decision tree incorporating all possible silvicultural practices and the associated biological responses would be immense and complex, and is unnecessary for the purpose of this paper. Instead, only a few silvicultural practices are considered in the decision tree presented in this paper. The decision tree in Figure 2 represents one of three identical networks. Each network stems from an initial decision on a regeneration practice. Ultimately, the model answers: What regeneration technique is financially best for a given postharvest stocking of desired tree species?

Decision Variables

Decision variables are those aspects of the problem that can be controlled by the decision maker. Decision variables in the model relate to the regeneration practice and the treatments for density or competition control. A single decision is allowed for final harvest. Similarly, failure of any regeneration strategy results in a single decision, namely replant. The cost and year of all treatments are summarized in Table 1.

The forest manager can choose from three regeneration practices: natural regeneration, fill planting, and site prep and planting. If stand establishment is successful, the decision maker may then choose to precommercial thin or not, in the case of natural regeneration or fill planting, or herbicide or not in the case of

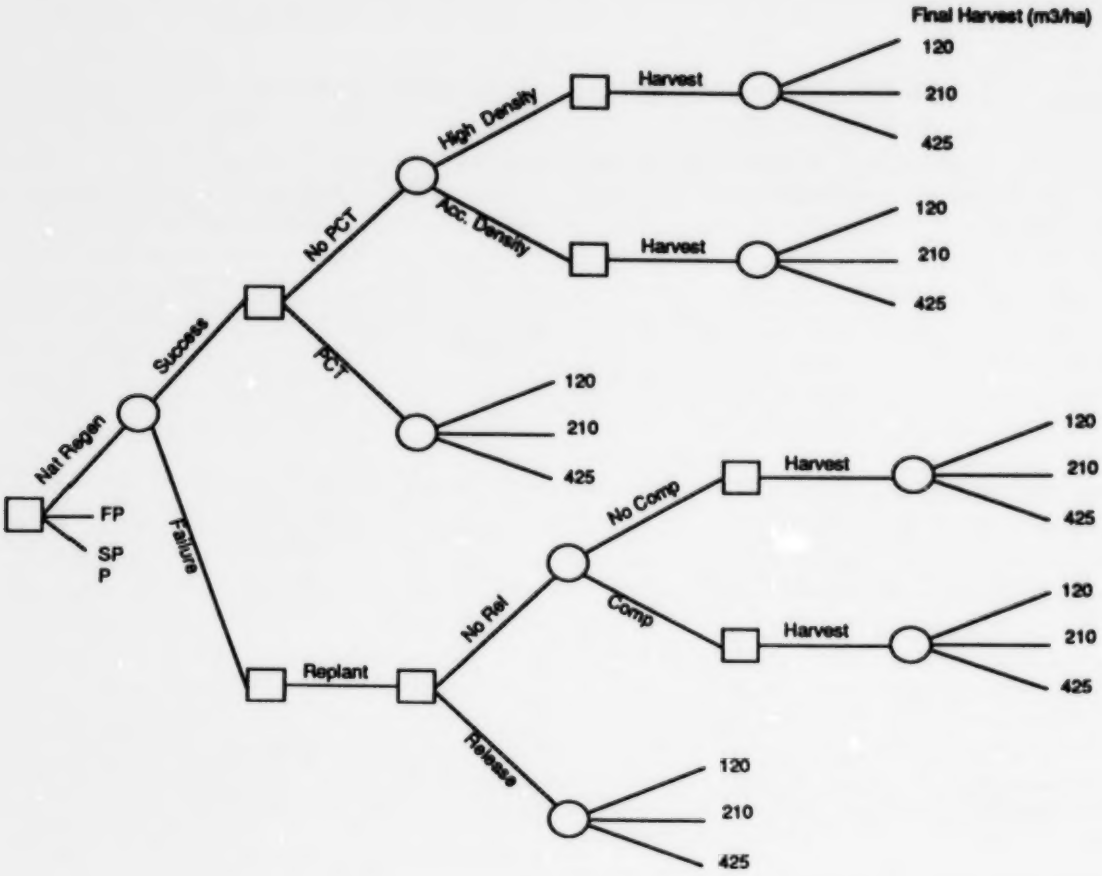

Figure 2 One third of a probabilistic decision tree for chosing a regeneration system given an initial stocking level

Table 1 Costs and years of the silvicultural practices specified in the decision tree

Item	Cost ($/ha)	Year of Occurrence	Comments
Fill Planting			
40 percent	$293	0	
50 percent	$280	0	
60 percent	$266	0	
Site prep/plant	$750	0	site prep: $250; plant: $500
Replanting			
Natural regen/fill plant	$750	5	Occurs if either treatment fails
Site prep/plant	$500	5	Includes herbicide
Precommercial thinning	$600	15	Occurs 15 years after successful stand establishment
Chemical Release	$150	2	Occurs 2 years after successful stand establishment

Table 2 The state variables and associated probabilities used in the decision tree

Probability of establishing 75% stocking by the 5th-year assessment given the initial stocking of:

Stocking (%)	Natural Regeneration	Fill Plant	Site Prep and Plant
40	.03	.56	.95
50	.17	.60	.95
60	.36	.70	.95

Note: Probability of failure = 1 - Probability of success

Probability of having a high density of stems/ha (> 20 000) or competition given that no thinning or chemical release is performed:

Stocking (%)	Natural Regeneration[a]	Fill Plant[a]	Site Prep and Plant[b]
40	.5	.7	.5
50	.6	.8	.5
60	.7	.9	.5

[a]If a stand is successfully established under either natural regeneration and fill planting, then high or acceptable density is possible without a thinning. For example, if initial stocking is 50% and site establishment is successful, then under natural regeneration the probability of high density is .6 and under fill planting .8

[b]If natural regeneration or fill planting fail to establish a stand, then replanting occurs and competition is a possibility. For example, if either natural regeneration or fill planting fail to establish the site with an initial stocking of 50%, then the site is replanted and the probability of competition is equal to .5, the same probability as under site prep and plant

planting. If the initial attempt at stand establishment fails, the site is replanted in year 5 to 2 500 stems/ha regardless of the initial regeneration strategy. Replanting is assumed to be successful. Site preparation is assumed to occur before replanting if natural regeneration or fill planting are the initial strategies. If replanting occurs after the first planting fails, a herbicide is applied to reduce competition prior to planting.

The second decision variable involves choosing density or competition control. If precommercial thinning (PCT) is chosen, the site is assumed to be thinned back to 2000 to 3000 crop trees per ha. PCT takes place 15 years after the site is established by natural regeneration or fill planting. An aerial herbicide application takes place 2 years after a site is prepared and planted.

The last decision variable involves the final harvest. Harvest yields and rotation age are based on expected yields for a site index 17 (base age 50) site. Yields per ha are treated probabilistically and are discussed in the following section. Rotation ages follow operability standards. A minimum stand volume of 120 m^3 per ha and a minimum average tree volume of 0.12 m^3 per tree.

State Variables

State variables represent the outcome of any decision, *i.e.*, the state of nature resulting from a chosen silvicultural practice or series of practices. State variables in the decision tree describe the stocking of a chosen regeneration practice, the density of stems per ha, the level of competition after planting, and the final harvest yield. A probability of occurrence is

associated with each state of nature. Probabilities were derived from a review of the literature on silvicultural practices and from expert opinion. These subjective probabilities are not exact, but represent relative differences in treatment responses. Probabilities are summarized in Table 2; the probabilities associated with harvest yields are not shown, but are available from the authors.

Regeneration Strategies

The stocking of each regeneration strategy after 5 years is used to describe success or failure of the treatment. It was assumed that initial stocking was distributed uniformly over the site. Success is defined as having a stocking of 75% (or 1875 stems/ha) of desirable tree species at the first regeneration assessment. The success or failure of a regeneration technique is tied to the initial stocking level. Three initial stocking levels, 40, 50, and 60%, were examined and the following set of hypotheses was used to explain the differences among the probabilities for the different regeneration practices and initial stocking level combinations:

1. The probability of success with natural regeneration increases as initial stocking increases.

2. The probability of success with fill planting also increases as initial stocking increases, but at a slower rate than the probability of success under natural regeneration.

3. The probability of success with fill planting is greater than the probability of success under natural regeneration for all initial stocking levels.

4. The probability of success with site prep and planting is the same for all initial stocking levels, and is greater than the probabilities of success under either natural regeneration or fill planting.

5. The probability of failure equals one minus the probability of success.

Stand density and competition

Studies by Godin (1986) and Zelazny (1987) indicate that even when the initial stocking level is low (20 to 50%), the number of stems per ha is often several thousand higher than desirable. To account for the possibility of different density levels a state variable was specified for two density levels, high and acceptable. For this exercise, acceptable density was defined as less than or equal to 15 000 stems per ha and high was greater than 15 000. High or acceptable densities are possible when a PCT is not prescribed. The probability of high or acceptable density levels depends on the initial stocking level and the regeneration strategy. It was assumed that the probability of high density with fill planting and no PCT was greater than the same probability given natural regeneration and no thinning.

When a site is planted, crop trees may experience competition from undesired vegetation. A state variable was specified to account for the possibility of having competition. This state variable was assumed to arise if a site was initially planted or replanted after failure of the initial regeneration treatment, and if the site was not treated with a herbicide. For all cases, the probability of having competition was assumed to be greater than the probability of no competition.

Harvest volumes

Growth and yield projections are usually based on the expected or average yield per ha under a specific set of silvicultural practices. The decision tree can incorporate a range of yields and the probabilities of achieving these yields. Three yields were used in this model: 120, 210, and 425 m^3 per ha. These merchantable pulpwood yields coincide, respectively, with the minimum operable volume per ha, the volume per ha under moderate forest

management, and the maximum volume per ha for the longest rotation age considered. The probability of achieving a given volume per ha depends on the silvicultural strategy leading to the final harvest, which, in turn, affects the rotation age at which the stand first becomes operable. Yields were derived from a diameter distribution model developed at the New Brunswick Department of Natural Resources and Energy.

Decision Criteria and External Variables

Two financial decision criteria were used to compare alternative silvicultural strategies: expected net present value (ENPV) and expected cost effectiveness (ECE). ENPV is the difference between the expected present value of harvest revenues and the expected present value of all treatment costs. The equation for ENPV is:

$$ENPV = \sum_{t=0}^{T} \frac{Revenues^t}{(1+i)^t} - \sum_{t=0}^{T} \frac{Costs^t}{(1+i)^t}$$

where:

t is the year a revenue is received or a cost incurred.
T is the total number of years of cash flow (*e.g.*, rotation age).
i is the interest or discount rate.

ENPV represents the profitability of a silvicultural strategy at some discount rate.

ENPV is derived by working right to left in the decision tree. At each state of nature node, the expected value, or weighted average of the outcomes is calculated. At each decision node, the decision with the expected value best meeting the decision makers objective is chosen. The silvicultural strategy which maximizes ENPV assumes the decision maker is a profit maximizer.

A stumpage price and discount rate must be specified to calculate ENPV. A stumpage price of \$6.00 per m^3 and a real discount rate of 3% were used as base values. All costs and prices were real or constant dollars, base year 1990.

Expected cost effectiveness indicates the value of the timber grown under a given silvicultural strategy, that is, its cost. ECE is derived from the future value of costs divided by the expected harvest yield. Only a discount rate needs to be specified for ECE; a 3% rate was used. The basic form of the ECE equation is:

$$ECE = \frac{\sum_{t=0}^{T} Costs^t \times (1+i)^{(T-t)}}{Harvest\ Volume^T}$$

The silvicultural strategy which minimizes the ECE assumes the decision maker is a cost minimizer.

MODEL APPLICATION

The results presented are intended to demonstrate the use of risk in a decision tree approach to assist in silvicultural decision making. They are not intended to define which regeneration strategy is "best" for an initial stocking level between 40 and 60%. Identification of such would require the user to adjust the model components and probabilities to reflect their unique situation. However, the model illustrates the potential of the approach and demonstrates the relationships between regeneration strategies, intermediate silvicultural treatments and the final harvest. Sensitivity analyses were conducted to determine which model variables (decision, state, or external), have the greatest effect on results.

Baseline Results

The site prep and plant strategy maximized ENPV (\$53.70) for initial stocking levels of

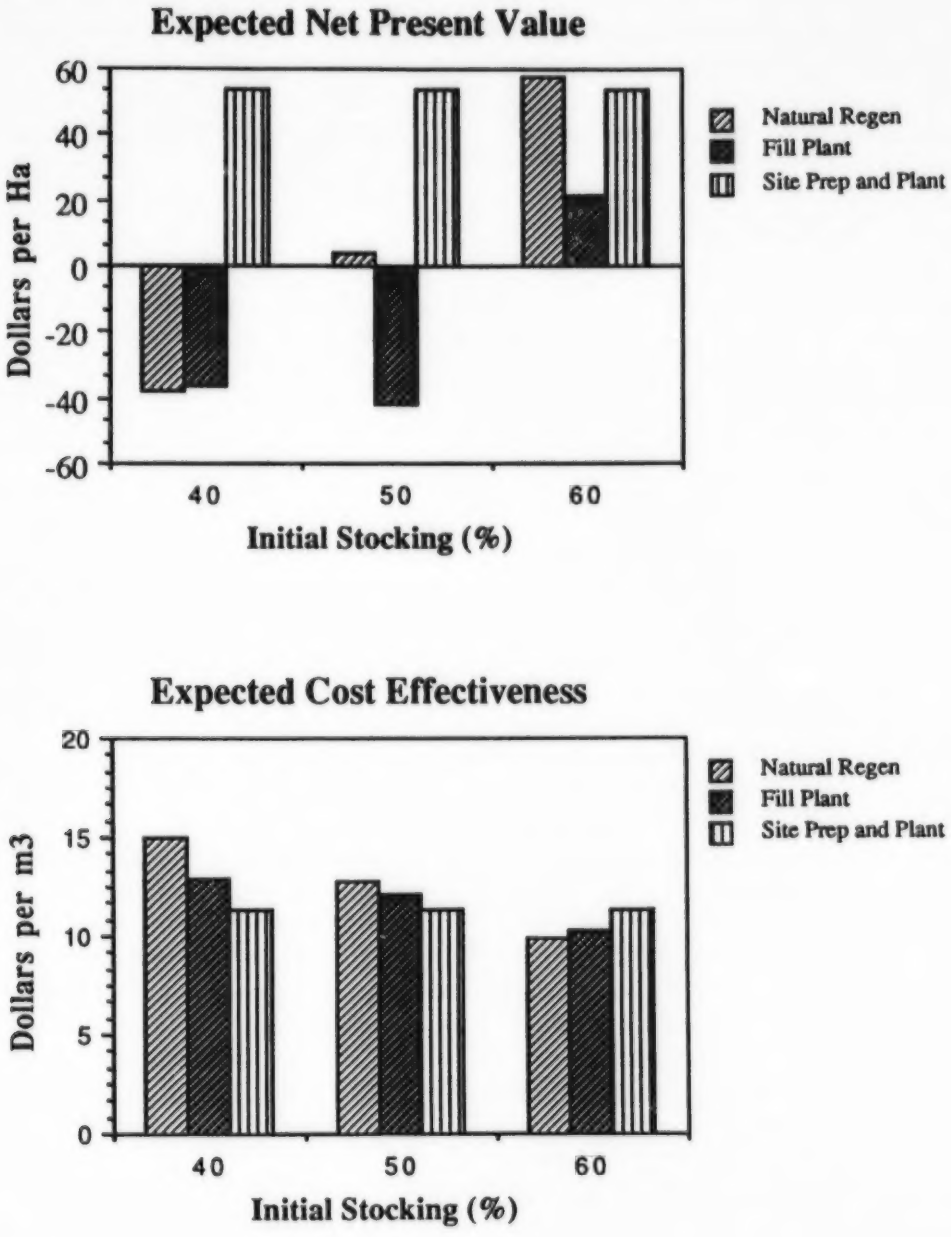

Figure 3 Expected net present value and expected cost effectiveness for three regeneration strategies and three initial stocking levels

40 and 50%. The ENPV for the natural regeneration strategy exceeded that for site prep and plant at 60% initial stocking ($57.66 versus $53.70) (Figure 3). Fill planting was the second best strategy at 40% stocking, but was ranked third at 50 and 60%.

These patterns seem logical given the trade-offs between risk reductions and cost increases. Even though natural regeneration and fill planting have lower costs than site prep and plant, their probabilities of success are less. This implies that the risk of failure under natural regeneration and fill planting out-

Table 3 The probability of success required to make the ENPV of a given strategy at a given stocking level equal to the first and second best strategy

Strategy	Initial Stocking (%)	Baseline	Best	Second
Natural Regeneration	40	.03	.35	.04
	50	.17	.35	-
	60	.36	-	.35
Fill Plant	40	.56	.73	-
	50	.60	.80	.70
	60	.70	.78	.77
Site Preparation and Plant	40	.95	-	.82
	50	.95	-	.88
	60	.95	.96	-

weighs the cost difference, and site prep and plant proves most profitable. At 60% stocking, the probability of successful stand establishment under natural regeneration increases enough to reduce the cost of risk, hence bringing its ENPV above that for site prep and planting. And even though fill planting increases the probability of establishing an acceptable stand over that of natural regeneration, the extra cost to fill plant does not justify the reduction in risk.

In terms of ECE, site prep and plant was the optimal strategy for initial stocking levels of 40 and 50%; the ECE value of \$11.26 per m^3 was the lowest of the three strategies (Figure 3). Fill planting was the second best strategy at these stocking levels followed by natural regeneration. The pattern reversed itself at 60% stocking.

Again, these patterns are logical; however the trade-offs seem to be between the expected rotation ages, expected harvest volumes, and treatment costs rather than risk reduction. Even though site prep and plant is the most expensive strategy, it has the shortest expected rotation age for any initial stocking level and the largest expected volume per ha for stocking levels 40 and 50%. Shorter rotations mean that costs are accumulated with interest for a shorter time. Under natural regeneration and fill planting, fuller site occupancy (stems per ha) at 60% stocking means greater expected harvest volumes which slightly offset the accumulated costs of longer rotations.

Sensitivity Analyses

Sensitivity analysis was carried out to: (1) to explore the flexibility of the model and (2) to identify general patterns about the regeneration strategies relative to the underlying conditions of the model. It should be noted that a specific decision regarding the best silvicultural strategy given different initial stocking levels cannot be made since probability estimates have not been completely validated.

Stumpage price and interest rate effects on ENPV

Figure 4 shows the regions of economic dominance, or maximum ENPV, for each regeneration strategy over a range of stumpage prices (\$1 to \$8 per m^3) and interest rates (1 to 7%). The boundaries between the regions indicate where the ENPV's for the respective strategies are equal. Patterns within and between initial stocking levels reveal aspects about the trade-offs between the costs and risks of the three strategies.

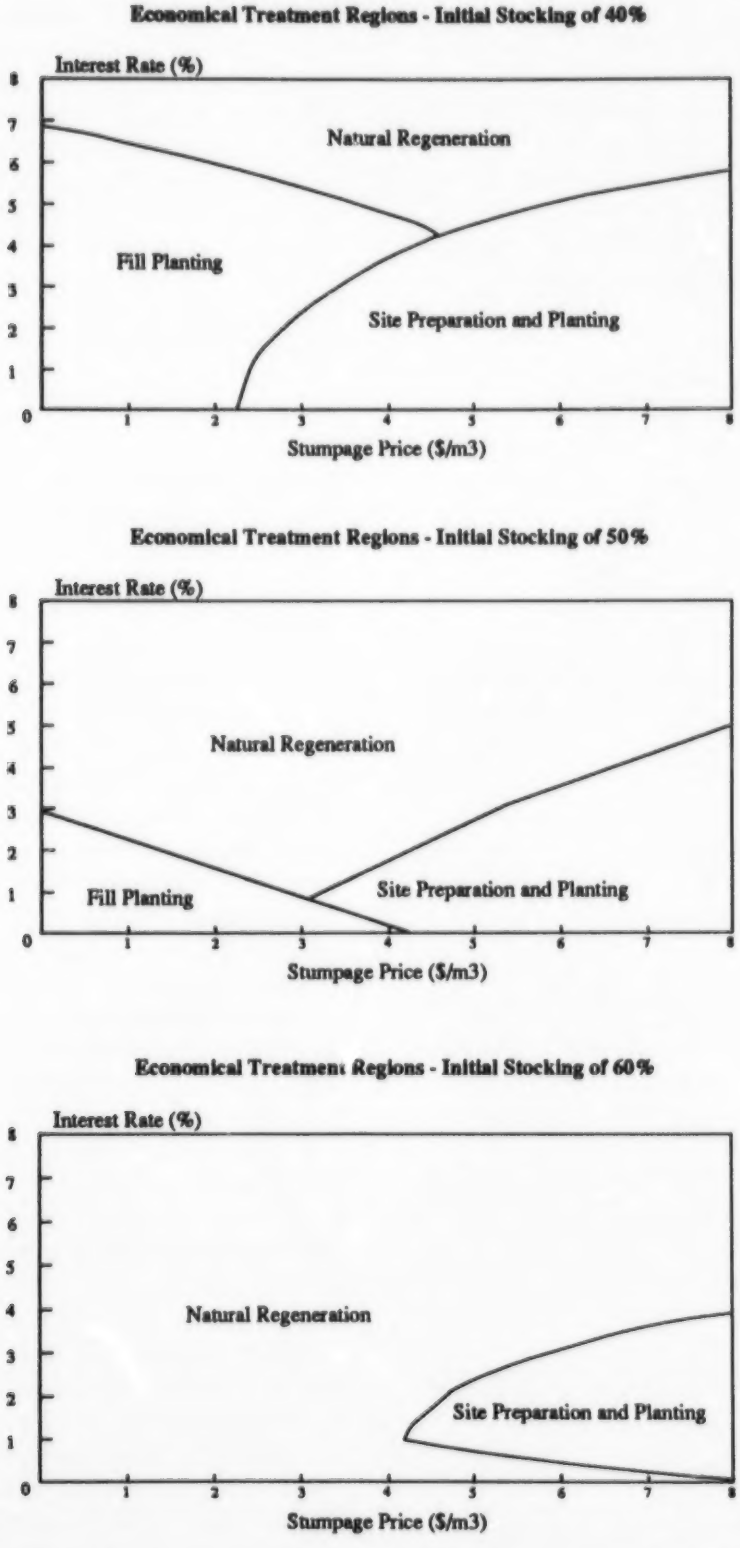

Figure 4 Dominance regions for expected net present value (maximum ENPV) with respect to stumpage prices and interest rates for three regeneration strategies and three initial stocking levels

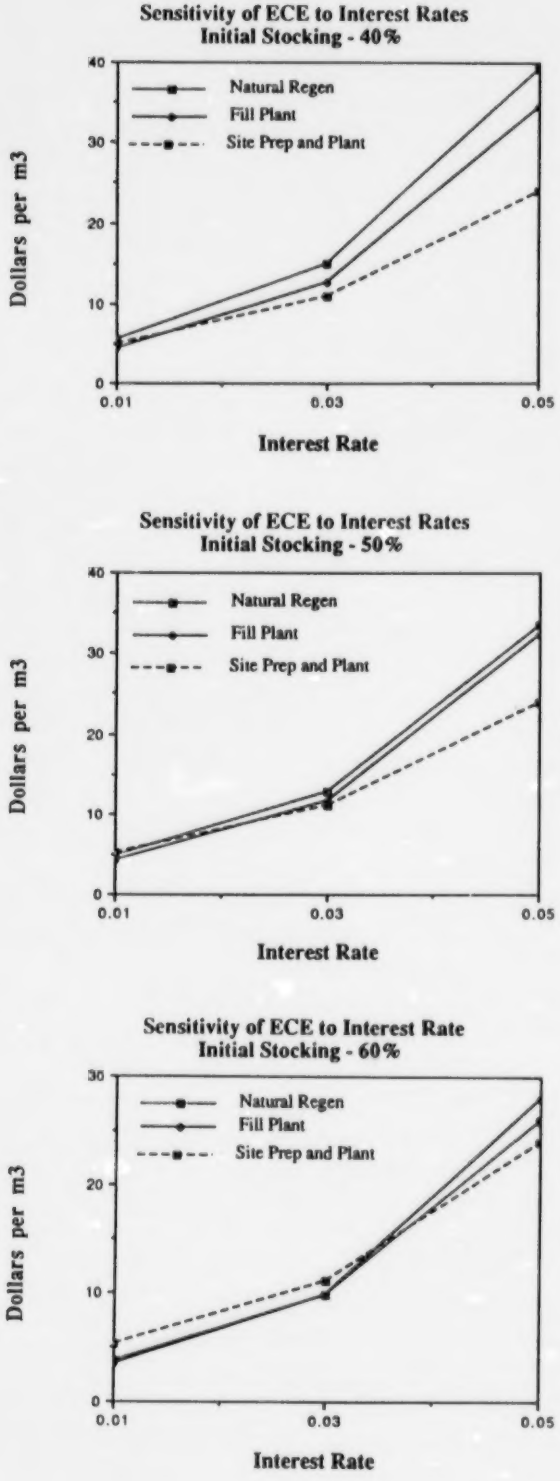

Figure 5 Sensitivity of expected cost effectiveness to changes in interest rates for three regeneration strategies and three initial stocking levels

Although the natural regeneration strategy had a lower probability of success and therefore greater risk than the other strategies, it dominated across all prices at high interest rates because it involves lower costs. Furthermore, it became an increasingly preferable option across a wider range of prices and interest rates as the initial stocking level rose, logically because the probability of success under natural regeneration increased.

The fill planting strategy was present in a dominant position at 40 and 50% stocking; however as stocking increased, fill planting was replaced by the natural regeneration option. This indicates that even though the probability of success for fill planting is higher than that for natural regeneration, the extra costs involved in fill planting become more important than the reduction in risk.

Finally, the site prep and plant strategy, with the highest cost and probability of success of all three options, required high stumpage prices and low interest rates to be most attractive. As with fill planting, the natural regeneration strategy slowly overtook the dominance region of the site prep and plant option. This indicates that the increase in the success of natural regeneration coupled with its low costs make it an increasingly preferable option over a wider range of stumpage prices and interest rates.

Interest rate effects of ECE

The relationships among the three strategies with respect to ECE were relatively stable over initial stocking levels and interest rates (Figure 5). The site prep and plant strategy had a lower ECE than the other strategies at interest rates equal to and greater than 1.5, 2.5, and 3.75% for stocking levels of 40, 50 and 60% respectively. Below these interest rates, either natural regeneration or fill planting had the lowest ECE. The ranking of the three

strategies was stable above an interest rate of 3.75%.

These relationships are consistent with the risk behavior of the three strategies. As the probability of success under natural regeneration and fill planting increases with initial stocking, the interest rates at which they are preferable also increase. In other words, a reduction in risk offsets some of the cost accumulation effects of raising interest rates.

Probability of success

The importance of the estimates of the probability of success was examined by seeing how much each probability would have to change to give a strategy the largest ENPV. The changes in the probabilities at 40% stocking were the highest of all stocking levels. The probability of success had to increase by 1067% for natural regeneration, by 30% for fill planting, and decrease by 14% for site prep and plant for each respective strategy to be superior compared to the other two. At an initial stocking of 50%, the changes were less; a 106% increase for natural regeneration, a 33% increase for fill planting, and a 7% decrease for site prep and plant. Finally, at 60% stocking, the changes were very small; a 3% decrease for natural regeneration, an 11% increase for fill planting, and an 1% increase for site prep and plant.

These results indicate several things. The ranking of preferred strategies is fairly robust with respect to changes in the probabilities at low stocking levels, but sensitivity increases as stocking increases. This behavior implies that estimates of the probabilities of success should be more accurate as the stocking level increases.

Site prep and planting costs

Site prep and planting costs could increase by as much as 14% before the preferred strategy changed. In terms of ENPV, fill planting became the preferred strategy at all stocking levels when site prep and planting costs were increased from $750 to $855 per ha because initial planting and replanting expenditures were affected. For the ECE criterion, the preferred strategy at 60% stocking changed from natural regeneration to fill planting when site prep and planting costs increased, but there was no strategy change at stocking levels of 40 and 50%.

Intermediate treatment costs

Increasing PCT costs had no effect on the preferred strategy at any stocking level. This occurs because the extra cost of PCT in conjunction with fill planting or site prep and planting was not justified by the relatively small increase in volume per ha.

Doubling the cost of chemical release ($150 to $300 per ha), however, made fill planting preferable at the 40% stocking level and natural regeneration better at 50 and 60% stocking according to ENPV. For ECE, doubling the release cost changed the strategy at 50% stocking from site prep and plant to fill planting.

Harvest volumes

Finally, decreasing volume yields by 15% (120 to 102, 210 to 178.5, and 425 to 361 m^3 per ha) made natural regeneration the preferable option at 50% stocking, instead of site prep and plant. This indicates that the volume gains from plantations are needed to offset the additional costs, regardless of the probability of success.

SUMMARY AND CONCLUSIONS

A probabilistic decision tree was constructed to examine regeneration strategies for initial stocking levels of 40, 50 and 60%. Decision variables included the regeneration strategy, intermediate treatments, and the final harvest.

State or probabilistic variables included the success or failure of the regeneration strategy, different density levels, the existence of competition, and final harvest yields. Two economic decision criteria were used to rank the regeneration strategies, expected net present value and expected cost effectiveness.

The model indicates the importance of recognizing risk in evaluating silvicultural decisions and the importance of recognizing the interrelationships of silvicultural prescriptions. Forest managers probably incorporate risk into their decision process already based on experience. The decision tree and economic analyses described here merely make these experiences with risk more explicit. In addition, the decision tree also integrates the expected gains and costs associated with combinations of silvicultural practices from initial stand establishment to final harvest.

Sensitivity analyses indicate that the preferred regeneration strategy depends on a number of the controllable and uncontrollable factors. When initial stocking levels are high, *i.e.*, greater than 60%, the ranking of the strategies was sensitive to changes in the probability of success. As such, estimates of probabilities must be more accurate at higher initial stocking levels than at lower stocking levels. The ranking of strategies is also sensitive to increases in site prep and planting costs and to decreases in final harvest yields.

The modelling process itself is simple and flexible. Decision and state variables can be added to or deleted from the decision tree as the decision maker desires. The model is limited, however, because of several factors. First, probability estimates are based solely on experience and expert opinion. Field validation of the probabilities of success should be a priority task before the model is used for operational decisions.

Second, a distance dependent, growth and yield model should be used to estimate the expected harvest volumes. Yield estimates used in the decision tree were obtained from a diameter distribution model and modified based on experience. While these estimates were fairly accurate for natural regeneration and site prep and plant strategies, they may have been inaccurate for the fill planting option.

Third, several rotation options for the final harvest could be incorporated into the model. Using the decision tree to identify rotation ages and expected harvest yield can provide a partial connection with forest level management targets.

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COMMERCIAL THINNING IN NEWFOUNDLAND

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Before beginning this talk, I'd like to say I'm particularly pleased to be here today for two reasons. First, there is such an interesting mix of operators, land managers, and researchers participating in this conference; and second, this is a conference on an important forestry topic being hosted or organized by the Department of Forest Engineering at U.N.B. When I was attending U.N.B., there was a great rivalry between the Forest Engineers and the other Forestry options; and I'm really pleased now to see both groups tackling these issues together. I'm sure we're all learning a lot from the exchange of information and ideas of the last two days.

Also, I'd like to acknowledge the contribution of two other forest engineers, both U.N.B. graduates, Bill Buggie and Eric Young, in assisting with this report. Much of the information presented today is from reports they currently have in print, and their Division has been most helpful in supporting projects.

INTRODUCTION

Newfoundland is the seventeenth largest island in the world; and, combined with Labrador, has a total land area of 35.6 million hectares. Its capital, St. John's, lies in a latitude two degrees south of Paris France; however, the cooling effect of the Labrador current dictates a less favorable climate than most similar latitudes.

Historically, the forest sector has been one of the three major industries in Newfoundland - the interior of which was initially opened up for white pine sawtimber production and later pulp and paper production. Prior to confederation with Canada in 1949, silviculture had consisted primarily of nursery production and planting by the Crown, and burning of cutovers by logging companies. Since Confederation, there have been a number of trials, with silvicultural operations reaching significant proportions in the last decade and a half.

In 1954-55, two large experimental pulpwood cuttings, termed commercial thinnings, were undertaken by Forestry Canada in cooperation with the AND Company and Bowater Newfoundland, near Badger and Deer Lake; in 1971-73, some six spacing trials were set up by the Province in various locations. Unfortunately, almost all these installations were lost to fire or insects and cutting, and solid information on commercial thinning in Newfoundland is limited.

Some 300 ha of forest have been commercially thinned in the province. Present activity consists of commercial thinning in small private woodlot holdings in the southwest portion of the province and of trials in Forest Management Unit 18. This paper addresses the latter trials.

FOREST MANAGEMENT UNIT 18

Forest Management Unit 18 (Roddickton Management Unit) comprises roughly half the Great Northern Peninsula and is presently entirely under Crown control. Climatic data indicates a frost-free season of approximately 110 days, 900 degree-days above 5°C, mean annual total precipitation of 1500 mm and annual potential evapo-transpiration of 300-350 mm. Parent soils are shale, slate, sandstone, quartzite, and calcareous sediments; zonal soils podzols. Productive forest

sites are mainly on Canadian Land Inventory forestry capability classes four to six (site indices 8 to 18). Major species in the Unit are balsam fir (*Abies balsamea* (L.) Mill.), white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) B.S.P.), and white birch (*Betula papyrifera* Marsh.) with corresponding percentage of cover types 93%, 1%, 5%, and 1%.

The production forest is managed primarily for commercial sawlog production, secondly for domestic requirements (individual's own permit for fuel, construction, and associated needs of that individual's household), and finally for biomass and commercial fuelwood needs. Following disturbance by cutting, the forest restocks to some 30 000 - 70 000 softwood stems/ha. To date, restocking has been adequate regardless of site, season of harvest, or equipment used in the harvesting activity (for the last 20 years, mainly cut and skid tree length). The silvicultural prescription on harvesting areas within the Unit has been to clearcut, accept the abundant natural regeneration, precommercially thin, and protect the crop until harvest.

The Unit is divided into three working circles or supply zones, of which the Central Working Circle has the greatest commercial harvesting activity. Past harvesting and other disturbance have left this working circle with a surplus in overmature, major shortfalls in the 40-60 and 60-80 age classes, a small surplus in 20-40, and an acceptable amount of 0-20. Of the overmature, approximately 40% are located on poor (marginally operable) sites with the entire overmature in high insect damage risk categories. Management plans of 1979 and 1987 indicate a major sawlog shortfall by the year 1999.

Given this forest age class structure, the existing harvesting and conversion infrastructure, and the dependence on this sustainable forest resource of a number of communities in the area, the approach to the situation seems obvious: concentrate silvicultural activity on the 20-40 year age class to offset predicted shortages (*i.e.*, minimize the interruption in flow of required forest material).

SPACING TRIALS (1987)

With environmental restrictions precluding an immediate possibility of forest fertilization operations, thinning was seen as the only means possible to bridge the gap between declining old growth forests and the abundant second growth forests in the 20-40 year age class (some 16 000 ha in the Central Working Circle alone). With this in mind, a 7.4-ha thinning of a 40-year-old stand was undertaken in October 1987 to three spacings of leave trees and with controls. Eight-, ten-, and fourteen-foot (2.4-, 3.0-, and 4.3-m) spacings were employed with salvage of felled stems as shortwood in 4- and 8-ft (1.2- and 2.4-m) lengths. Buffers of 15-m unthinned material were maintained around thinned areas to protect against possible wind damage, while one exposed area was thinned to the widest spacing with no buffer to observe the effect of wind. Permanent sample plots were established in all spacings and controls.

Unit technical staff ribboned leave trees (generally those of largest diameter and best form) in an initial portion of each spacing to familiarize silviculture workers with desired spacing and selection of leave trees. Felling and processing was by chainsaw with wood piled along predetermined lines, usually at the center of 15- or 20-m strips. The six silviculture workers and foreman involved, while experienced in harvesting and precommercial thinning, had no experience in commercial thinning. The motor-manual felling, processing, and piling constituting the thinning treatment covered from 0.034 to 0.110 ha per person-day. Production (*i.e.*, area treated) generally decreased from the 8- to 14-ft spacing, but no appreciable difference was found between length of shortwood salvaged. Lowest 2-week cost was $1200/ha

($485/acre), but it is felt costs under $1000/ha are attainable in a single spacing done by private contract, with foreman and overhead costs distributed over a larger crew.

Initial densities ran from 11 000 to 27 000 stems/ha and basal area from 53 to 90 m^3/ha. Basal area removed averaged 75%, which seems amazing but is understandable given that half the basal area was from stems less than 10 cm dbh, considered sub-merchantable. Volume was reduced by approximately 40% with average dbh of stems remaining 14.7 cm (5.8 in). Average diameter of stems salvaged was 12.5 cm (4.9 in).

Extraction

Over the 7.4-ha trial, 505 m^3 (210 cords) of shortwood was salvaged, implying some 68 m^3/ha (11.4 cords/acre) is immediately generated from thinning these stands. The majority of this volume was removed by snowmobile and sled at no expense to the Crown within a few months of termination of the thinning. "Roads" were assigned to interested domestic cutters and their activity was monitored by Unit staff.

In the summer of 1988, Headquarters Forest Products Division removed a further 120 m^3 (50 cords) to roadside using a portable log winch (Log-Ox) and mini-skidder (Combi-Track). A limited amount of 3.6-m (12-ft) spacing with extraction of salvaged full trees was done at this time for comparison.

The Log-Ox, essentially a more heavily designed (if not over-designed) version of the Radio-Horse, gave production of 4.76 m^3 per productive machine hour (PMH) skidding 2.5 m wood using a cone, 4.17 m^3/PMH skidding 1.2 m wood in bundles, and 3.1 m^3/PMH skidding full tree. Production was similar to that reported for other similar systems, and overall cost was estimated at $4.54/$m^3$. Stumps in haul roads, or "racks", had to be kept low.

The Combi-Track, generally used as a mini-skidder hauling long lengths, was used as a mini-forwarder in shortwood extraction. Production average 1.1 m^3/PMH forwarding in each of 2.4- and 1.2-m lengths, and 1.5 m^3/PMH skidding full tree. Extraction ranged from $21 to $29/$m^3$. The Combi-Track had no difficulty negotiating slope, but stumps had to be cut as low as possible, as with the Log-Ox, and debris removed from haul roads.

Damage to leave trees and site was minimal with skidoo, slightly greater with Combi-Track, and greater again with Log-Ox, particularly along racks where cable rub and bumping/scraping of trees was evident. A means of decreasing this damage would be to leave extra trees along the rack that could be thinned as extraction proceeded. Regardless, the amount of damage overall to trees and site was considered acceptable with either of these three means of extraction.

THINNING TRIALS 1989

In 1989, additional information was sought on a larger mini-forwarder and fully mechanized system for commercial thinning. Contracts were let by Forest Products and Development Division to Jim ver Boom of Nova Scotia for thinning with extraction by F-4 Dion Forwarder and to Jamestown Lumber Company for a small feller-buncher and skidder system.

Manual Felling/F-4 Dion

Stand and site conditions were similar to previous trials and again, thinning would be classed as a low thinning. Of the 7.6-ha block, 2.6 ha were thinned to 3 m (10 ft) leave tree spacing, while the balance was 3.6-m (12-ft) spacing. Motor-manual felling, delimbing, and bucking processed merchantable stems to 2.4-m lengths which were piled throughout strips. Production of silviculture workers averaged 0.11 ha per person-day (pd) (0.27 acres/pd), producing 7 m^3/pd (2.9 cords/pd) under a favorable wage system with quality

checks. Blocks and operational layout were by the silviculture contractor.

Extraction was by means of the F-4 Dion mini-forwarder. This machine, originally manufactured by Bombardier for James Bay development application, is similar to the more familiar J-5, except that it is equipped with a loader and the powered trailer is a standard feature. 478 m^3 (198 cords) were salvaged over the 7.6 ha, producing 63 m^3/ha (10.6 cords/acre). Approximately 40% of the merchantable basal area and 33% of the merchantable volume were removed. F-4 Dion production averaged 0.10 ha/PMH (0.25 acres/PMH) or 6.13 m^3/PMH (2.5 cords/PMH).

Due to the encouraging results of this system, an additional area was scheduled for tree section thinning (*i.e.*, felled trees are not delimbed but bucked in more random lengths and piled for extraction). Motor-manual production was acceptable, but volume per forwarder load was decreased (2.4 green tonnes/PMH). Modifications to the trailer bunk for tree section operations could make this system more viable.

Feller-Buncher/Skidder

The mechanical thinning system used consisted of a Morbell feller-buncher (a small three-wheeled machine with an accumulating shear head designed for harvesting in lower volume merchantable stands), and a conventional wheeled, cable skidder. The idea was to thin alternate rows of the 2.25-ha block, then travel the thinned "roads" and reach into unthinned strips to thin the remaining forest.

The reach of the felling head was limited to 1.8 m (6 ft), which dictated that the initial leave strips could only be 3.6 m (12 ft) wide. Additionally, the width of the smallest skidder available (and to some extent the feller-buncher) dictated a clearcut strip again of 3.6 m (12 ft). Although the Morbell (and smaller conventional skidders) may well be suited to commercial thinning of plantations in the southern United States, it is clear that a felling head on an extendable boom and mini-skidder or forwarder would be better suited to local conditions. However, it was the only completely mechanized system available, and it was accepted to see what information it could provide. Within its inherent limitations, the system proved well; and operator ability enabled extending the width of leave strips from 3.6 m (12 ft) to 4.3 m (14 ft) partway through the trial.

As expected, total basal area removed was quite high at approximately 72% for both widths of initial leave strips. Volumes produced were high, due to salvage of virtually all sub-merchantable and merchantable non-crop trees presented as full trees at the landing. Tonnage produced was 167 green metric tonnes(gmt)/ha (roughly equivalent to 143 m^3/ha (59 cords/acre)) with a feller-buncher production of 3.04 m gmt/PMH and skidder production by bundling of 2.92 gmt/PMH.

Damage Assessment

Detailed assessment of site disturbance (ground damage) and damage to leave trees was conducted with both systems of heavier thinning equipment. Site disturbance was measured through a line and plot method noting disturbance as percentages in five categories. Damage to leave trees was assessed through modification of a Finnish system noting, among other things, distance from center line of extraction route, distance from root collar, damage size, reason for damage, and equipment component causing damage.

Basic results were that the feller-buncher/skidder system caused five times as much leave tree damage and three times as much ground disturbance as the man/forwarder system. Of the 7% tree damage, major causes were rubbing of stems and root

breakage. While it is recognized that these trials were undertaken in late fall and likely represent worst cases due to wet ground conditions, there is still room for improvement; for example, with the man/forwarder system, placing tops in haul roads and possibly leaving rub trees along trails to be removed later, as suggested with the logging winch.

Despite heavy snow loadings and winds since 1987, there has been surprisingly little blowdown, breakage, or noticeable wind damage. It was anticipated that the first 2 years would be an indication of wind damage; thus far, the indication has been favorable, with negligible damage recorded in permanent sample plot remeasurement or observed in field. Even the most heavily thinned feller-buncher/skidder trial has not shown appreciable damage in its first winter, although it is possible that the trees were frozen in the ground shortly after the treatment was completed.

GROWTH AND YIELD

Permanent sample plots (PSPs) have been established in commercial thinnings done to date, although it is anticipated treated areas will be in a state of shock for 2 to 3 years, and will not show increased growth response in this period. Initial remeasurement of 1987 PSPs shows diameter increase at about 3% and height growth estimated at about 0.10 m on average.

The merchantable mean annual increment (m.a.i.) of average growing stock in the Unit is 1.78 m^3/ha/yr (0.32 cords/acre/yr). Furthermore, it is commonly accepted that merchantable volume extracted from managed stands is in the order of two to seven times that of natural stands on the same site. Cross-checking curves developed for thinning used in FORMAN modelling with two times the natural yield on this site (less present removals) gives a minimum expected merchantable volume on this site of 260 m^3/ha (44 cords/acre) within a 20-year period. Local volume tables verify the diameter size at a 3.6-m (12-ft) spacing of 30 cm (12 in) and at a 3.0-m (10-ft) spacing of 26 cm (10 in) dbh. The spruce component of the stand can also be changed from some 6% to 40% through thinning, if so desired.

COSTS

A downfall of commercial thinning in several jurisdictions has been the cost of extracting salvaged timber to roadside; one may even suggest that the name "commercial" thinning is a misnomer. Systems such as the portable winch or mini-forwarder may be viable, and at operating costs shown, both the Log-Ox and Combi-Track may have application in certain economic situations, usually small scale on privately owned land. The F-4 Dion and totally mechanical system, on average, operated hauls three to four times that of the lighter equipment and had total costs of \$28.41/m^3 and \$42.83/gmt, respectively.

However, it is a fact of life that, in Canada, silviculture is done mainly under federal-provincial cost-sharing arrangements that specify certain payment amounts, usually on a per hectare basis, for certain types of silviculture treatments. Considering what appears to be the most promising system for a larger operational program, the man/F-4 Dion forwarder system, the following prices would provide favorable conditions for new equipment, industry wages, and a rate of return of 20%:

Grant (\$/ha)	Roadside Purchase Price (\$/m^3)
0	31.50
400	25.15
450	24.40
500	23.50
750	19.60

The latter two prices are not out of line with rates paid in the private woodlot program or in Nova Scotia.

Certainly, it can be seen that at prices less than that being paid for other silviculture treatments, especially combinations of sequenced treatments, thinning in age-class 2 can be a viable proposition for silviculture contractors and can generate silvicultural and employment benefits. Additionally, it will provide economic benefits in the form of a more immediate return on a shorter period to harvest, more valuable stems of larger piece size, and maintenance a more evenly regulated flow of desirable material to forest harvesting and processing facilities.

CONCLUSIONS

1. Thinning can be done in age-class 2, with acceptable levels of damage to site and leave trees, and with apparent wind firmness of leave trees almost 3 years after thinning. Initial indications of growth response are good.

2. Equipment such as log winches and mini-skidders have potential for certain economic conditions, such as private woodlot ownership, or possibly pre-bunching for other equipment or larger operations. The man/small forwarder thinning system can be economic on larger operations under silviculture payments less than that of existing silviculture treatments or series of treatments.

3. Substantial amounts of fiber are generated at present (up to 68 m^3/ha) and diameters of crop trees can be expected at 26 to 30 cm dbh within 20 years.

4. Tree section thinning should be investigated further operationally.

5. Applied research possibilities exist in growth and yield information which can be related to site and damage incurred.

6. The Central Working Circle of Newfoundland's Forest Management Unit 18 has an age-class distribution showing major shortfalls within 10 years. A sound management objective would be to operationally thin as much of the 16 000 ha in age-class 2 as possible, and consider staged thinnings in the 4 200 ha already precommercially thinned in the Unit. To do otherwise, necessarily dictates severe decline in the forest industry sector, particularly sawmilling, in the foreseeable future.

ADDENDUM

Several graphs, worksheets, and pictorials to accompany this paper are available on Lotus or Ventura diskettes from Forest Products Division, Dept. of Forestry and Agriculture, P.O. Box 2006, Corner Brook, Nfld., A2H 6J8. Maps and overheads used are available from the author, Dept. of Forestry, Box 250, Roddickton, Nfld., A0K 4P0.

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FOREST REGENERATION OPTIONS IN BOREAL FORESTS

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ABSTRACT

Various factors are discussed that must be considered prior to choosing a forest regeneration method in the boreal forest. These forests are typically adapted to regenerate following disturbance, and it is therefore important to first understand what controls natural regeneration. In many cases, unassisted natural regeneration is sufficient, but it can also be enhanced by forest management practices, such as partial canopy removal, site preparation or weed control. Artificial regeneration is used as a management tool when the species, density, distribution, or condition of natural regeneration is unsatisfactory. The criteria used to design a regeneration regime should include the choice of species, the minimum and maximum acceptable properly-distributed stand density, and a measure of minimum acceptable regeneration performance. The complexity of choosing among options favors the development of decision support tools such as expert systems that are able to encode knowledge and professional rules and link with secondary programs or geographic information systems. These tools will help silviculturalists define their criteria for choosing among regeneration systems and help in determining the best choice in a particular instance.

INTRODUCTION

Based on recent estimates, approximately 1000 000 ha per annum of Canadian forest are harvested for timber (Kuhnke 1989) and wildfire burns about 2 000 000 ha per annum (Van Wagner 1988). Insect and disease epidemics are more difficult to quantify but may lead to the destruction of almost 600 000 ha per annum (Honer and Bickerstaff 1985). Finally, an unknown area of forest is cycled continuously via windthrow, canopy gap replacement, and stem or root diseases.

Most forests regenerate naturally; the annual area planted in Canada, about 400 000 ha in 1988, is a small portion of the total area disturbed (Kuhnke 1990, unpub. data). However, planting programs tend to be centered on the accessible, commercially viable tracts of forest land and represent a large public investment. Furthermore, there is a public perception that areas harvested are not regenerating naturally, that regeneration programs in Canada have failed to date, and that more artificial regeneration is required. Thus, an understanding of the ecological processes of forest regeneration and how management can stimulate or change those processes is of great importance to forest management agencies, both in terms of program formulation and in responding to the public's concerns.

This paper will discuss the biological determinants of forest regeneration, and how they relate to boreal tree species and their response to harvesting, fire, insect epidemics, or canopy gap creation. Finally, I will use some contemporary ecological theories to suggest a framework for considering how management treatments will affect the composition and productivity of forest regeneration. The objective is to show that forest managers in Canada do not succeed or fail in regenerating the forest, but in defining and meeting their management objectives. Those management

Table 1 Comparative environmental conditions for tree species regeneration after three disturbance types, compared with the conditions in the understorey of an undisturbed forest

Variable	Clearcut	Burned	Insect-killed	Undisturbed understorey
Light intensity	high	high	moderate	low
Nutrient availability	high	high	high	low
Soil moisture availability	high	high	high	low
Soil surface moisture	low	moderate	moderate	moderate
Soil temperature	low	high	low	low
Soil surface temperature	high	high	low	low
Vapor pressure deficit	high	high	moderate	low
Frost incidence	high	high	moderate	low
Wind speed	high	high	moderate	low
Competition dynamics	high	moderate	moderate	low
CO_2 concentration in air	high	high	high	low

objectives relate to the density, distribution, dominance, and growth of preferred species on a site after disturbance.

CONCEPTS OF FOREST REGENERATION

Disturbance

Boreal forests are well adapted to and even dependant on periodic disturbance. The disturbance may be as dramatic as a 1 000-ha wildfire or as minor as a clump of trees being windthrown. In the different bioclimatic regions of the boreal forest, different disturbance regimes prevail. For example, the boreal forest of northwestern Ontario is relatively dry and subject to continual major forest fires. The Acadian forests of western Newfoundland, Cape Breton, and the Gaspe, however, are wetter and less likely to be consumed by fire. In these areas, forests tend to be cycled by insect epidemic. Much of the high elevation forest of the Rocky Mountains trench of western Canada is also too moist to burn and these forests cycle continuously via windthrow or disease pockets in stands.

The type of disturbance that cycles a forest will affect the conditions available for regenerating tree species. For example, Margolis and Brand (1990) suggest differences in the conditions that occur at the ground surface after harvesting or fire, compared with the undisturbed understorey. I have also included the case of a forest that has been destroyed by insect attack, namely the hemlock looper, in Newfoundland (Table 1). The table indicates the types of factors that tree species must be attuned to if they are to respond to disturbance and colonize or recolonize a site. For example, white spruce, which regenerates naturally in canopy gaps or understorey conditions, is poor at withstanding late spring frosts. On the other hand, jack pine can withstand frosts or high vapor pressure deficits when grown in the open following fire, but cannot survive low light conditions in the understorey. The table also partly explains why some species persist and dominate in some regions but others do not. Aspen, jack pine, and lodgepole pine, for example, are centered in regions with higher fire frequencies. Balsam fir is found in eastern Canada where fire is less common, insect epidemics cycle most forests, and understorey regeneration is necessary.

Adaptation and acclimatization of tree species to post-disturbance conditions

Tree species, like other plant and animal species, evolve to fill niches. That is, through mechanisms associated with seed production, seed longevity, germination requirements, tolerance to stress, and efficiency in the use of light, moisture, or nutrients, they have adapted to respond to a certain type of disturbance and achieve dominance over their competitors. For example, jack pine is well-adapted to regenerate after wildfire. The species holds seed for many years, stored in serotinous cones. When fire kills the stand, the cones open and shower seed on the burned seedbed. The species is then able to use the readily available resources of light, moisture, and nutrients efficiently and initially grows very rapidly. But, in the case of a patch of windthrow, the species is at a disadvantage for the same reasons: it cannot effectively disburse or successfully germinate seed, and it has poor shade tolerance.

In addition to adaptation, species vary in their ability to acclimatize or adjust to changes in conditions. Balsam fir, for example, regenerates under the forest canopy and grows slowly in a suppressed condition. After an insect epidemic, the saplings can acclimatize to the change in light, moisture, and nutrient availability and begin to grow rapidly to recolonize the site. Several other tree species, such as white spruce, use this strategy for regeneration and growth into canopy gaps. There seems to be a trade-off, however, as rapidly growing, pioneer-type tree species are less able to acclimatize to shade or other stresses than tolerant or late successional species.

Environmental conditions and tree growth

The growth of a tree is the result of its absorption of carbon, water, and nutrients and the incorporation of these materials into tissues. Carbon and nitrogen-based molecules are the primary building blocks of growth and the tree must balance the uptake and assimilation of these materials to maximize growth (Waring and Schlesinger 1985). Many environmental conditions limit the absorption or use of these resources, including temperature, light intensity, soil moisture tension, and nutrient mineralization rates. In addition, these conditions change dramatically over the course of a growing season, between growing seasons, and along successional gradients. Thus, each tree species, to remain viable from one generation to the next, must be able to regenerate and grow under some range of conditions that give it a competitive advantage over other species.

Trees can be adapted to be highly efficient in resource use and grow rapidly or they can be very conservative in resource use and be able to withstand stress (Grime and Hunt 1975). All trees must balance the use of assimilated carbon and nitrogen between current growth and storage. Storage products allow the rapid flushing of boreal tree species in the spring when growth rates exceed the uptake of resources (Iwasa and Cohen 1989). The fact that species vary in their respective allocation of resources between growth and storage is one of the underlying principles differentiating stress tolerant from stress intolerant species. In addition, trees adjust to imbalances in the supply of carbon, water, and nutrients by redirecting growth to tissues that absorb the most limiting resource (Hunt and Lloyd 1987). Thus, tree species can buffer changes in environmental conditions and survive and grow in both changing and periodic levels of resource availability. Lodgepole pine and interior spruce, for example, vary in terms of their response to different sets of environmental conditions (Table 2). Under conditions of poor carbon uptake and readily available nitrogen, the trees build up nitrogen products in their tissues and allocate proportionately less growth to roots. Under conditions of high carbon uptake and poor nitrogen availability, the reverse is true; trees build up starch and sugars in their tissues and increase proportional allocation of growth to roots. Note also that

Table 2 Nitrogen and starch concentrations and proportion of growth allocated to roots by lodgepole pine and interior spruce growing in contrasting environments

Species	Treatment	1st growing season N	Starch	RWR	2nd growing season N	Starch	RWR
Lodgepole pine	- cold soil, high nutrients, no competition	1.99	4.5	.22	1.98	3.2	.13
	- warm soil, limited nutrients, heavy competition	1.41	12.1	.23	1.51	2.6	.15
Interior spruce	- cold soil, high nutrients, no competition	1.74	6.6	.18	2.13	4.3	.14
	- warm soil, limited nutrients, heavy competition	1.16	15.1	.25	1.21	6.6	.19

the more tolerant spruce has a higher concentration of starch than pine under any set of conditions. From this it can be seen that spruce is less well adapted to cope with the type of conditions that occur after a major disturbance.

Competition and dominance

Despite satisfactory inherent conditions on a site, the access of a given species to resources will be restricted by the presence of other species competing for those resources. The pattern and outcome of competition in the regeneration phase is a function of the timing and method of regeneration of different species, resource capture, and resource use efficiency. For example, trembling aspen produces suckers after fire, allowing the species to use carbohydrates stored in its roots for rapid initial shoot growth. Pin cherry has extended seed longevity in the forest floor and, when disturbance occurs, the stored seed germinates quickly followed by rapid growth. These pioneering species grow open extended crowns, maximizing the capture and use of high intensity light. They are very efficient at using light, moisture, and nutrients for growth, but are not shade tolerant. They must, therefore, outgrow their competitors and reach dominance of the site if they are to survive. Many common commercial tree species are of this seral type, including jack pine, red pine, lodgepole pine, and larch.

Another strategy to cope with competition is stress-tolerance and the ability to survive and grow without achieving dominance of the site. These species, through efficient leaf area display, storage of sugars and starch, and low respiration rates, are able to grow in an understorey position and wait for the shorter-lived seral species to die. While responding to improved levels of light, moisture, and nutrient availability, these species are inherently more conservative in their growth rates than seral species. Conifers of this type include white spruce, balsam fir, and cedar.

IMPACT OF MANAGEMENT ON FOREST REGENERATION

One way to consider the impact of forest management activities is in relation to the natural ecology of the tree species being grown. In the following sections, the ecological implications of major forest management operations are considered.

Canopy Removal

The most radical forest management treatment is the removal of the canopy through harvesting. A wide range of environmental conditions are all changed at once and any understorey plants or advanced regeneration must acclimatize to increased light intensity, much higher atmospheric water vapor demand, and a higher incidence of summer frosts. In most cases, due to poor cuticular development and limited stomatal control, the understorey vegetation is stressed or killed by canopy removal and, if surviving, must rebuild foliage acclimatized to the new conditions before effective growth response can occur.

Canopy removal also stimulates natural regeneration by buried seed, sprouting and suckering of cut stems, and germination of current seed rain. Seed lying dormant in the forest floor is particularly well suited to respond after harvest, owing to the lack of forest floor destruction. Species such as raspberry, elderberry, and pin cherry are examples of this type of regeneration strategy. The forester may consider an initial partial canopy removal if the objective is to protect advance regeneration and minimize the development of competitors. Alternatively, by harvesting in winter, the understorey vegetation will be best able to acclimatize to the new set of environmental conditions with the current flush or growth.

Advance, natural, or artificial regeneration methods

Forest managers can also greatly influence the character of the regenerating forest by the choice of regeneration method. Advance regeneration requires that harvesting be carried out carefully to protect saplings in the understorey. If advance regeneration is insufficient, of poor quality, or of an inappropriate species, then treatments can be used to discourage or destroy it. Natural regeneration following harvest can be encouraged by modification of forest floor conditions to improve seedbed conditions, by strip cutting or seed tree cutting, or by leaving branches and cones on site in the case of jack pine or black spruce. Artificial regeneration is useful when insufficient advance or natural regeneration is expected, when a species or genotype change is desirable, or where forest productivity and economics justify higher levels of investment to produce higher yields than available through natural methods.

Site preparation

Site preparation treatments are used in post-harvest natural regeneration or artificial regeneration systems. Objectives of the treatment vary, but can include forest floor disturbance to improve survival of germinants, distributing cones in the case of black spruce and jack pine slash, increasing soil temperature, improving aeration and drainage, increasing nutrient mineralization rates, and physically disturbing competing vegetation. From an operational perspective, site preparation can also be used to improve access for planting or seeding, and to make planting of individual trees easier. But site preparation treatments can also have negative consequences, such as soil erosion, loss of nutrients through leaching or displacement, soil drying, frost heaving, and improved germination of wind-dispersed seed from competitive species. These conflicting effects lead to differences in response among different site types.

Fertilization

Fertilizing sites after harvest to stimulate advance regeneration has not been studied extensively. In general, limited growth response has been found to fertilizing regeneration in boreal forest conditions (Brockley 1988). This can be attributed to the low nutrient demand of the small trees and the flush of nutrients occurring after harvesting. However, growth

Table 3 Growth of various spruce and pine species in response to different reforestation treatments

Treatment	Stem volume (cm^3), 3 seasons after planting					
	White spruce	White pine	Black spruce	Jack pine	Interior spruce	Lodgepole pine
Planted only	33	51	0.5	5	6	16
Fertilized	38	68	1	11	9	6
Scarification	55	68	6	33	28	71
Weed control	102	201	18	124	20	31
Scarification and weed control	185	235	32	210	38	131
Scarification, weed control, and fertilization	231	331	47	331	49	216

responses to fertilization can be significant when site preparation and weed control have been concurrently applied (Table 3).

Vegetation control

The typical pattern of forest succession varies among site types. Some forests are stable from generation to generation, usually due to the nature and frequency of disturbance. For example, jack pine in central Canada, balsam fir in the east, and trembling aspen in the mixedwood regions are fairly stable and well-adapted to respond to fire or insect epidemic. However, when attempts are made to regenerate forests following harvest, or with species different from the natural pattern of regeneration, some form of vegetation control is often necessary to favor the desired species.

Experiments have shown that competing vegetation influences growth of crop trees dramatically, regardless of whether overtopping occurs. Growth rates of crop trees generally decrease as the degree of overtopping by competing vegetation increases (Brand 1986). Thus, treatments that decrease the physical size and space occupied by competing vegetation generally increase growth rate of crop trees. In a study of regeneration requirements of conifers (Brand and Janas 1988; Brand and Penner 1990), competition indices were measured around crop trees in plots subjected to different experimental treatments. In general, competition indices were reduced by both site preparation treatments and vegetation control treatments (Table 4) and this was strongly linked with growth responses (Table 3).

Density control

Advance or post-harvest natural regeneration methods give little or no control over the density and distribution of crop trees. In the case of balsam fir and pines particularly, many sites regenerate overabundantly. This results in slow growth due to intraspecific competition and is frequently countered by juvenile spacing or precommercial thinning (Johnstone 1985; Janas and Brand 1988; Brown 1989).

Stand density is also controlled by modifications to the regeneration method. Sites with poor initial stocking or with stocking of commercially undesirable species may be candidates for scarification for natural regeneration or for planting. This gives greater control of crop species composition and, in the case of planting, of stand density. Janas and Brand (1988), for example, found

Table 4 Average values of competition indices on three research sites in different regions of Canada in relation to experimental treatments

Treatment	Site		
	Chalk River, Ont. (Aspen-Pine)	Timmins, Ont. (Aspen-Spruce)	Prince George, B.C. (Spruce)
	Competition index value (mid-third growing season)		
Planted only	116	281	291
Planted and scarified	75	46	33
Planted and weed control	1	5	2
Planted, weed control, and scarification	2	1	1

Competition index (CI) values are calculated as:

$CI=(Hb/Ht)\bullet(\%Cb)\bullet((Rb/Rt)+1)^{-1}$ where Hb is average height of weed species, Ht is height of crop tree, %Cb is the percent cover of the weed species in a 1.41 m tree-centered plot, Rb is the average distance to the weed species from the tree stem, and Rt is the average width of the tree crown. Further details can be found in Brand (1986).

Table 5 Stand characteristics of plantation and naturally regenerated jack pine after 21 growing seasons[a]

Stand attribute	Natural stand	Plantation	
		2.13-m spacing	4.27-m spacing
Whole stand			
Stems/ha	9875	1961	544
Total volume (m^3)	131	169	79
Mean height (m)	8.3	12.3	10.8
Mean dbh (cm)	5.6	13.3	18.5
Largest 400 trees/ha			
Merchantable volume (m^3)	7	44	57
Mean height (m)	10.9	13.1	11.1
Mean dbh (cm)	11.3	16.8	19.6

From Janas and Brand (1988)

that postfire jack pine, if allowed to regenerate naturally, produced stands with a density greater than 9 000 stems/ha at age 25. This led to much slower growth than areas where natural regeneration was destroyed and planting carried out (Table 5).

FOREST REGENERATION OBJECTIVES

Faced with a confusing set of decisions relating to harvesting method, species choice, regeneration method, and silvicultural treatment, managers need a framework within which to evaluate alternative choices. One way to simplify the decision-making process is to set biological criteria upon which to evaluate various options, and then to economically analyze the options against those criteria to choose a "best" alternative.

Species

From a managerial perspective, the choice of species for reforestation will rely on three biological criteria: the productivity of the potential species on the site, the reliability of the species, and the silvicultural feasibility of growing the species (Klinka and Feller 1984). Productivity is determined from site classification schemes linked with estimates of growth and yield. Productivity can include both the volume produced and its economic value. The reliability of a species relates to considerations such as susceptibility to insect or disease attack, fire, and windthrow, and is a measure of risk. Finally, the silvicultural feasibility is a measure of the amount of input necessary to successfully manage for the species. On some sites, for example, it is too difficult to convert a site from one species to another, or it would require an excessive and uneconomic number of operations.

Stocking, density, distribution

When choosing the management regime for a particular species or species mix, stand density is of primary concern in controlling the time it takes to reach merchantable tree size, estimating harvesting costs, and computing the final value generated from the stand. Stand density, however, only gives a measure of the total number of stems per ha and does little to indicate total site occupancy or distribution (Brand 1988). In assessing natural regeneration, for example, it is often the case that while density per ha is high, total site occupancy is not. This results from patchy or clumped tree distribution. Conversely, the need for precommercial thinning may be localized in those areas with dense regeneration.

To set criteria for regeneration, it is necessary to define some way of evaluating minimum and maximum threshold values for commercially valuable tree species. This means that at some point the potential value generated by thinning, fill planting, or rehabilitating the stand exceeds that of allowing the stand to develop on its own. Minimum stocking and maximum density values cannot realistically be developed as provincial standards, for example, as each stand has a different set of economic constraints affecting its potential value.

Regeneration establishment and the free-growing point

Reforestation programs carried out for commercial purposes also require criteria for judging success or the need for intermediate treatments. Regeneration can be considered established if it is growing at a rate considered suitable for the site, with a low risk of mortality. The free-growing point is found when the desired crop species reaches an age, size, and growth rate that indicates it will not be overtopped by competing vegetation and is destined to form the main canopy of the stand on the site concerned. The criteria for setting free-growing standards on a site go beyond the potential for tree survival, however, and must relate to the potential growth response of trees to competition control.

CHOOSING A REFORESTATION REGIME

The foregoing discussion indicates the complexity involved in choosing the "right" reforestation regime for a particular site. Not only do tree species vary in their site requirements, productivity, and susceptibility to potential risks, but silviculturists can modify site conditions dramatically to favor one species over another. Each combination of site type-species-silviculture regime that is possible must be evaluated against treatment costs, time to harvest, and final product value. Increasingly, these problems of choice are being solved by decision-support tools that embed biological rules, economic analysis, and operational constraints in an expert system. A simple expert system for choosing tree species for artificial regeneration was recently described by Rice *et al.* (1989). The system requires information on climate and site conditions from the user and indicates the suggested species or possible species for the site.

Further development of these systems could include growth and yield estimates for different species, estimates of the impact of certain silviculture treatments on growth, and an economic evaluation of alternative regeneration regimes.

CONCLUSION

This paper has presented an overview of the regeneration ecology of boreal tree species, the relationship of forest management practices to that regeneration ecology, and has proposed criteria upon which to evaluate the potential choices facing a forest manager in making reforestation decisions. Due to the complexity of the forest regeneration decision-making process, the development and use of expert systems is suggested. In the final analysis, forest regeneration on any site can take a number of courses, and success or failure can only be evaluated against what the forest manager was trying to accomplish.

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APPENDIX I - PROGRAM

Conference on
NATURAL REGENERATION MANAGEMENT

Program

Tuesday, March 27

8:00 - 8:45 a.m. **Registration**

8:45 - 9:00 a.m. **Opening Remarks:** David MacFarlane (NB Department of Natural Resources and Energy, Fredericton, NB)

9:00 - 12:00 p.m. **Prediction of Advanced Registration in Precut Stands**

Moderator: Blair Hodgson (NBIP, Dalhousie, NB)

Papers:

"***Use of an Ecological Classification to Evaluate Regeneration and Competition Problems After Clearcutting***", Brian Harvey (Université du Québec, en Abitibi-Témiscamingue, Rouyn-Noranda, PQ)

"***Predicting the Occurrence of Natural Softwood Regeneration: Experience in New Brunswick***", Vince Zelazny (NB Department of Natural Resources and Energy, Fredericton, NB

"***Variations in the Abundance of Advanced Fir Regeneration in Principal Fir Ecological Types of the Balsam Fir Stands in Central Quebec***", Louis Bélanger (Université Laval, Sainte-Foy, PQ)

"***Prediction of Advanced Regeneration: Quebec Experience***", David Chamberlain (Stone Consolidate, PQ)

12:00 noon Lunch (provided)

1:00 - 5:00 p.m. **Harvesting Impacts on Advanced Regeneration**

Moderator: Dave Mason (Stone Consolidated, Bathurst, NB)

Papers:

"***Natural Regeneration from Sprouts and Advanced Growth***", David M. Smith (Yale University, New Haven, CT)

"***Effects of Forest Floor Disturbance on Soil Seed Banks, Germination and Early Survival After Clearcutting a Northern Hardwood Stand in Central New Brunswick***", Bryce McInnis (University of New Brunswick, Fredericton, NB)

"***Natural Seed Regeneration of Black Spruce Stands After Fire and Strip Cutting in the Quebec Boreal Forest***", Réjean Gagnon (Université du Québec, Chicoutimi, PQ)

"***Advance Growth Abundance and Regeneration After Commercial Clearcutting in Quebec***", Jean-Claude Ruel (Ministère de l'Énergie et des Ressources, Sainte-Foy, PQ)

"***Physiological Response of Balsam Fir and White Birch to Precommercial Thinning***" (Hank Margolis, Université Laval, Ste-Foy, PQ)

5:00 p.m. **IUFRO World Congress 1990** (D. Hall)

Wednesday, March 28

8:00 - 12:00 noon **Characterization of Regeneration Quality and Abundance**

Moderator: Jan Ellingsen (Miramichi Pulp and Paper Inc., Newcastle, NB)

Papers:

"***Growth Performance of Mature Second-Growth Black Spruce Trees in the Saguenay-Lac St-Jean Region, Quebec***", Jean-Martin Lussier (Université du Québec, Chicoutimi, PQ)

"***The Establishment and Early Growth of Red Spruce and Balsam Fir Regeneration***", Patrick Strauch (Resource Conservation Services, Inc., Bangor, ME)

"***The Role of Released Advance Growth in the Development of Spruce-Fir Stands in Eastern Maine***", William Davis (Yale University, Sewanee, TN)

"***Natural Regeneration Assessment Methods for Quality and Quantity***", David Maass (The Irland Group, Augusta, ME)

"***The Influence of Stocking of Regeneration on the Yield of Natually Regenerated Black Spruce Stands***", Rene Doucet (Ministere de l'Energie et des Ressources, Sainte-Foy, PQ)

12:00 noon Lunch (provided)

1:00 - 4:30 p.m. **Silvicultural Options to Reach Yield Targets in Naturally Regenerated Stands**

Moderator: Bob Seymour (University of Maine, Orono, ME)

Papers:

"***Herbicide Technology for Securing Natural Regeneration of Spruce-Fir***", Maxwell McCormack (University of Maine, Orono, ME)

"***Early Respnse of Balsam Fir to Precommercial Thinning in the Context of Site Quality***", Russell Briggs (University of Maine, Orono, ME)

"***Fill planting to Achieve Yield Targets in Naturally Regenerating Stands***", Ted Needham (University of New Brunswick, Fredericton, NB)

"***Identification and Economic Evaluation of Stand Establishment Strategies***", Stephen Clements (University of New Brunswick, Fredericton, NB)

"***Commercial Thinning in Newfoundland***", Bill Clarke (Department of Forestry, Roddickton, NFLD)

"***Criteria for Choosing Among Forest Regeneration Alternatives***", David Brand (Forestry Canada, Petawawa, ON)

4:30 p.m. **Closing Remarks**: Gordon Baskerville (Faculty of Forestry, University of New Brunswick, Fredericton, NB)

APPENDIX II - LIST OF PARTICIPANTS

NAME	COMPANY	LOCATION
Adams, Greg	J.D. Irving Ltd.	Sussex, N.B.
Anderson, Bill	Forestry Canada - Maritimes Region	Fredericton, N.B.
Annis, Peter	St. Croix Pulpwood Ltd.	McAdam, N.B.
Bailey, Tim	N.S. Dept. of Lands and Forests	Addington Forks, N.S.
Balch, Si	Boise Cascade	Rumford, ME
Banfield, Malcolm	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
Barr, Robert W.	Georgia-Pacific Corp.	Woodland, ME
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NAME	COMPANY	LOCATION
Croman, Stephen	Georgia-Pacific Corp.	Woodland, ME
Daigle, Bernard	Forestry Canada - Maritimes Region	Richibucto, N.B.
Dann, Mike	Seven Islands Land Co.	Mapleton, ME
Davis, William	The University of the South	Sewanee, TN
DeFranceschi, Joe	Forestry Canada - Northwest Region	Edmonton, AL
Deschenes, Bertrand	Fraser Inc.	Edmundston, N.B.
Deveau, Fernand	SENB Forest Products Mktg. Bd.	Shediac, N.B.
Dickinson, Charles	Valley Forest Products Ltd.	Nackawic, N.B.
Doucet, René	Min. de l'Énergie et des Ressources	Ste-Foy, P.Q.
Duke, Hermel	DNRE	Bathurst, N.B.
Dunlap, Jerry	Juniper Lumber Co.	Juniper, N.B.
Eash, J. Michael	Great Northern Paper Company	Millinocket, ME
Eldridge, Brian	Lunenburg Co. For. Mgmt. Group	Bridgewater, N.S.
Ellingsen, Jan	Miramichi Pulp & Paper Inc.	Newcastle, N.B.
Emrich, Walter	J.D. Irving Ltd.	Sussex, N.B.
Erdle, Thom	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
Estey, Melvyn	Forestry Canada - Maritimes Region	Fredericton, N.B.
Etheridge, Peter	J.D. Irving Ltd.	Sussex, N.B.
Fajvan, Mary Ann	University of Maine	Orono, ME
Faulkner, Lee	J.D. Irving Ltd.	St. George, N.B.
Floyd, Charles	J.D. Irving Ltd.	Sussex, N.B.
Francis, Peter	N.S. Dept. of Lands and Forests	Bridgewater, N.S.
Gagnon, Réjean	Université du Québec	Chicoutimi, P.Q.
Gagnon, Roland	J.D. Irving Ltd.	Saint John, N.B.
Gauthier, Ron	DNRE	Bathurst, N.B.
Gilbert, Leon	S.D. Warren Company	Jackman, ME
Gilmore, Daniel	University of Maine	Old Town, ME
Glynn, Michael	Atlantic Waferboard Inc.	Chatham, N.B.
Gorten, Greg	International Paper Co.	Stratton, ME
Haines, David	N.S. Dept. of Lands and Forests	Lawrencetown, N.S.
Hall, Dal		Nepean, Ont.
Hamilton, Bill	DNRE, Forest Extension Branch	Fredericton, N.B.
Hamilton, Ian	Alberta For. Ser., Reforestation Branch	Edmonton, Alta.
Harvey, Brian	Université du Québec	Rouyn-Noranda, PQ.
Hayter, Mike	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
Hebb, Darrel	DNRE	Newcastle, N.B.
Heinstein, Carl	NBIP	Dalhousie, N.B.
Herron, Jason P.	St. Croix Pulpwood Ltd	McAdam, N.B.
Higgs, Brian	Valley Forest Products	Nackawic, N.B.
Hobbins, Dave	University of Maine	Fort Kent, ME
Hodgson, Blair	NBIP Forest Products Inc.	Dalhousie, N.B.
Hongyun, Dong	University of New Brunswick	Fredericton, N.B.
Hovey, Carl	YFS Forest Marketing Board	Fredericton, N.B.
Hoyt, Steve	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
Hughes, Peter	N.B. Fed. of Woodlot Owners Inc.	Fredericton, N.B.
Hunt, Tony	University of Moncton	Edmundston, N.B.
Hutchinson, P. Jon	P.E.I. Dept. of Energy and Forestry	Charlottetown, P.E.I.
Hynes, Kevin	J.D. Irving Ltd.	Saint John, N.B.
James, Peter	N.S. Dept. of Lands and Forests	Bridgewater, N.S.
Jeglum, John	Forestry Canada - Ontario Region	Sault Ste. Marie, Ont.
Johnson, Jean-Nil	SENB Forest Products Mktg. Bd.	Shediac, N.B.
Jones, Patrick	Forestry Canada - Maritimes Region	Oromocto, N.B.
Joudrey, Gerry	N.S. Dept. of Lands and Forests	Truro, N.S.
Kanach, R.	S.D. Warren Company	Jackman, ME
Kilpatrick, Brian	Forestry Canada - Maritimes Region	Fredericton, N.B.
Labbe, Vern	Maine Bureau of Public Lands	Presque Isle, ME

NAME	COMPANY	LOCATION
Laplante, Jean-Louis	DNRE	Edmonston, N.B.
Laweryson, Kenneth	S.D. Warren Company	Bingham, ME
Lawson, Lafay	DNRE	Fredericton, N.B.
LeBlanc, Gabriel	SENB Forest Products Mktg. Bd.	Shediac, N.B.
LeBlanc, Steve	Champion International	Ellsworth, ME
Leclair, Jean-Guy	North Shore Forestry Syndicate	Bathurst, N.B.
Lees, Jock	Forestry Canada - Maritimes Region	Fredericton, N.B.
Lepack, Anne	YSC Forest Marketing Board	Fredericton, N.B.
Levasseur, Guy	DNRE	Edmundston, N.B.
Levesque, Jacques	DNRE	Edmundston, N.B.
Logan, Art	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
Ludwig, Pete	Champion International	Bucksport, ME
Lussier, Jean-Martin	Université du Québec	Chicoutimi, P.Q.
Maass, David	The Irland Group	Augusta, ME
MacFarlane, David	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
MacFarlane, Derek	Forestry Canada - Maritimes Region	Fredericton, N.B.
MacFarlane, Lloyd	J.D. Irving Ltd.	Sackville, N.B.
MacLaggan, Robert	DNRE	Fredericton, N.B.
MacLean, Edward	North Inverness For. Mgmt. Ltd.	Margaree Fks., N.S.
MacMillan, Thomas	N.S. Dept. of Lands and Forests	Yarmouth, N.S.
Maillet, Marcel	SENB Forest Products Mktg. Bd.	Shediac, N.B.
Malloy, Wayne	Forestry Canada - Maritimes Region	Fredericton, N.B.
Marcedo, Mike	International Paper Co.	Bangor, ME
Marchand, Stéphane	Université Laval	Québec, P.Q.
Margolis, Hank	Université Laval	Ste-Foy, P.Q.
Mason, David	Stone Consolidated Inc.	Bathurst, N.B.
McAllister, Kenneth	S.D. Warren Company	Bingham, ME
McCarthy, Pat	NBIP	Dalhousie, N.B.
McCarthy, Randy	N.S. Dept. of Lands and Forests	Truro, N.S.
McCarthy, Wayne	Juniper Lumber Co.	Juniper, N.B.
McCormack, Max	University of Maine	Orono, ME
McDonnell, Daniel	Miramichi Pulp & Paper Inc.	Chatham, N.B.
McInnis, Bryce	University of New Brunswick	Fredericton, N.B.
McKay, Richard	DNRE	Fredericton, N.B.
McLaughlin, Jim	DNRE	Hampton, N.B.
McLean, Dave	J.D. Irving Ltd.	Sussex, N.B.
McNally, Russ	N.S. Dept. of Lands and Forests	Truro, N.S.
Moller, Rolf	DNRE, Forest Extension Branch	Fredericton, N.B.
Moore, Ken	Minas Basin Pulp & Paper Co. Ltd.	Hantsport, N.S.
Morin, Hubert	Université du Québec	Chicoutimi, P.Q.
Muise, Robert, L.	N.S. Dept. of Lands and Forests	Yarmouth, N.S.
Murphy, Daniel	DNRE	Bathurst, N.B.
Murray, Tom	Forestry Canada - Maritimes Region	Fredericton, N.B.
Navratil, S.	Forestry Canada - Northwest Region	Edmonton, Alta.
Needham, Ted	University of New Brunswick	Fredericton, N.B.
Ng, Tom	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
Niederleitner, Joe	DNRE, Fish & Wildlife Branch	Fredericton, N.B.
Noble, Terry	Fraser Inc.	Edmundston, N.B.
Nowlan, Ron	Forestry Canada - Maritimes Region	Tracadie, N.B.
O'Brien, Don	DNRE, Forest Extension Branch	Fredericton, N.B.
O'Brien, Tim	N.S. Dept. of Lands and Forests	Truro, N.S.
Olson, Larry	Dept. of Nat. Res. - Forestry	Hibing, MN
Patenaude, Pierre	J.D. Irving Ltd.	Saint John, N.B.
Paterson, Russel	Forestry Canada - Maritimes Region	Oromocto, N.B.
Pelletier, Gaetan	J.D. Irving Ltd.	Saint John, N.B.
Pembroke, Rick	S.D. Warren Company	Jackman, ME

NAME	COMPANY	LOCATION
Peters, Gerry	Stora Forest Industries Ltd.	Pt. Hawkesbury, N.S.
Price, Manley	NBIP	Dalhousie, N.B.
Prosser, Doug	Agfor Ltée	Fredericton, N.B.
Quartermain, Walter	Forestry Canada - Maritimes Region	Oromocto, N.B.
Rainer, Elizabeth	DNRE	Bathurst, N.B.
Rayworth, Colin	Forestry Canada - Maritimes Region	Fredericton, N.B.
Reed, John	DNRE, Timber Mgmt. Branch	Fredericton, N.B.
Reid, Tom	DNRE	Fredericton, N.B.
Richard, Paul	SNB Wood Cooperative Ltd.	Sussex, N.B.
Richardson, Larry	Georgia-Pacific Corp.	St. Stephen, N.B.
Ritz, George	Maine Bureau of Public Lands	Old Town, ME
Robe, Steve	S.D. Warren Company	Bingham, ME
Roberts, Mark	University of New Brunswick	Fredericton, N.B.
Robertson, Ron	N.S. Dept. of Lands & Forests	Truro, N.S.
Robichaud, Hector	DNRE	Bouctouche, N.B.
Robichaud, Peter	Forestry Canada - Maritimes Region	Truro, N.S.
Robinson, Charles	University of the South	Sewanee, TN
Ross, Hugh	Stora Forest Industries Ltd.	Pt. Hawkesbury, N.S.
Rouselle, J. Ronald	DNRE	Bathurst, N.B.
Roy, Roland	Madawaska Forest Prod. Mktg. Bd.	Edmundston, N.B.
Ruel, Jean-Claude	Min. de l'Énergie et des Ressouces	Ste-Foy, P.Q.
Salonius, Peter	Forestry Canada - Maritimes Region	Fredericton, N.B.
Savard, Richard	Synd. Prod. Bas-St-Laurent	Rimouski, P.Q.
Schaertl, Dick	Monsanto	Orono, ME
Schmidt, Kirk	North Mountain Woodland	Middleton, N.S.
Scott, Merlyn	Forestry Canada - Maritimes Region	Oromocto, N.B.
Seymour, Bob	University of Maine	Orono, ME
Singleton, Julie	YSC Forest Marketing Board	Fredericton, N.B.
Small, Tom	International Paper Co.	
Smith, David	Yale University	New Haven, CT
Smith, Kevin	Forestry Canada - Maritimes Region	Oromocto, N.B.
Smith, Peter	Maine Bureau of Public Lands	Farmington, ME
Somerville, Fred	Valley Forest Products Ltd.	Nackawic, N.B.
Spencer, Chris	SNB Wood Cooperative Ltd.	Sussex, N.B.
Spinney, Tom	DNRE	Fredericton, N.B.
Steinman, Jim	University of Moncton	Edmundston, N.B.
Sternweiss, Stefan		West Germany
Stone, Lewis	J.D. Irving Ltd.	Saint John, N.B.
Strauch, Patrick	Resource Conservatin Services Inc.	Bangor, ME
Sullivan, Cameron	N.S. Dept. of Lands and Forests	Truro, N.S.
Sutherland, Donald	North Colchester Forest Co-op	River John, N.S.
Swift, Ed	Forestry Canada - Maritimes Region	Fredericton, N.B.
Talbot, Réjean	Forestry Canada - Maritimes Region	Edmundston, N.B.
Tardie, Don	Fraser's Maine Timberlands	Ashland, ME
Tibbetts, Barry	S.D. Warren Company	Bingham, ME
Toole, Dean	Forestry Canada - Maritimes Region	Sussex, N.B.
Topolniski, Kevin	Fraser Inc.	Edmundston, N.B.
Torunski, John	Maritime Forest Rander School	Fredericton, N.B>
Trencia, Jacques	Forestry Canada - Laurentian Region	Ste-Foy, PQ
Trevors, Joe	H.J. Crabbe & Sons Ltd.	Bristol, N.B.
Ung, Chhun-Huor	Forestry Canada - Laurentian Region	Ste-Foy, PQ
Van Buskirk, Tony	Miramichi Pulp & Paper Inc.	Newcastle, N.B.
Veitch, George		St. John's, Nfld.
Vessie, Blair	DNRE	Bathurst, N.B.
Von-Tobel, Ernie	Boise Cascade	Rumford, ME
Waite, Ron	SENB Forest Products Mktg. Bd.	Shediac, N.B.

NAME	COMPANY	LOCATION
Waldron, Leigh	DNRE	St. Stephen, N.B.
Walker, Richard	DNRE	Rogersville, N.B.
Wall, David	Miramichi Pulp & Paper Inc.	Newcastle, N.B.
Walters, Karl	Carelton-Victoria Wood Prod. Assoc.	Bristol, N.B.
Wang, Eric	N.B. Exec. Forest Research Comm.	Fredericton, N.B.
Wasser, Ron	J.D. Irving Ltd.	Sussex, N.B.
Watts, Mike	International Paper Co.	
Weeks, Kenneth	St. Croix Pulpwood Ltd.	McAdam, N.B.
Weigelt, R.	S.D. Warren Company	Jackman, ME
West, Andrew	J.D. Irving Ltd.	Saint John, N.B.
White, Alan S.	University of Maine	Orono, ME
White, Brian	N.S. Dept. of Lands and Forests	Truro, N.S.
White, Kenneth	Seven Islands Land Co.	Presque Isle, ME
Whitworth, Tom	Maine Forest Service	Fort Kent, ME
Woods, Doug	Fraser Inc.	Plaster Rock, N.B.
Woods, Timothy	Champion International Corp	W. Stewartstown, NH
Young, Eric	NFLD Dept. of Forestry	Corner Brook, NF
Zelazny, Vince	DNRE, Timber Mgmt. Branch	Fredericton, N.B.